BIOASTRONAUTICS

CRITICAL PATH ROADMAP

(BCPR)

BASELINE DOCUMENT

An Approach to Risk Reduction and Management for Human Space Flight

July 30, 2003
Rev D

CHANGE RECORD

Rev	Description	Originator/Phone	CPCP Approval Date or Other Outcome
Baseline	*Baselined Version*	*L. Leveton/USRA-BCPR (703-916-0643)*	*5/08/00*
A	*CR-001: Change in Critical Questions 6.09 and 6.22*	*B. Woolford/JSC (281-483-4010)*	*8/30/00*
B	*CR-002: Change in Risk No. 47 and CQ No. 11.33*	*M. Gernhardt/JSC (281-244-8997)*	*1/16/01*
	Editorial revisions	*L. Leveton/USRA-BCPR (703-916-0643) & J. Charles/JSC (281-483-7224)*	*Multiple dates*
C	*CR-003: Change title of Risk #9*	*S. Bloomfield, NSBRI-TAMU (979-862-1181)*	*Not accepted due to non-concurrence by JSC co-lead L Shackleford*
	CR-004: Change priority score of CQ 2.25	*S. Bloomfield, NSBRI-TAMU (979-862-1181)*	*1/17/02*
	CR-005: Revise CQ 2.11 into 2 separate CQs	*S. Bloomfield, NSBRI-TAMU (979-862-1181)*	*1/17/02*
	CR-006: Delete CQ 2.23	*S. Bloomfield, NSBRI-TAMU (979-862-1181)*	*1/17/02*
	CR-007: Change wording of CQ 2.24	*S. Bloomfield, NSBRI-TAMU (979-862-1181)*	*1/17/02*
	CR-008: Change priority score of CQ 2.24	*S. Bloomfield, NSBRI-TAMU (979-862-1181)*	*1/17/02*
	CR-009: Change wording of CQ 2.26	*S. Bloomfield, NSBRI-TAMU (979-862-1181)*	*1/17/02*
	CR-010: Change priority score of CQ 2.26	*S. Bloomfield, NSBRI-TAMU (979-862-1181)*	*1/17/02*
	CR-011: Change priority score of CQ 2.21	*S. Bloomfield, NSBRI-TAMU (979-862-1181)*	*1/17/02*
	CR-012: Multiple changes to Risks 33, 34 and 35 (Table 6.9)	*C. Oman/NSBRI-MIT (617-253-7508) M. Reschke/JSC (281-483-7210)*	*1/17/02—partially accepted; remainder to be resubmitted as appropriate*
	CR-013: Multiple changes to Risks 22, 23 & 27, CQs 7.21-7.29	*W. Shearer/NSBRI-Baylor College of Medicine (832-824-1274)*	*1/17/02—partially accepted on advice of C. Sams, JSC co-team lead*
	CR-014: Multiple changes to Risk 39	*F. Cucinotta/JSC (281-483-0968)*	*1/17/02—partially accepted (name change only)*
	CR-015: ALS Rank Reduction for ISS-only CPR case for Risk 53	*K. Daues/JSC (281-483-1370)*	*1/17/02*
	Editorial revisions (corrections)	*J. Charles/JSC (281-483-7224)*	*3/27-28/02*
C+	*Editorial revisions*	*J. Charles/JSC (281-483-7224) & L. Leveton/USRA-BCPR (703-916-0643)*	*4/2-3/02*
C++	*CR Form Changes*	*L. Leveton/USRA-BCPR (703-916-0643)*	*6/11/02*
D	*Editorial revisions and multiple CRs for DCS,*	*L. Leveton/USRA-BCPR (703-916-0643) & J.*	*7/30/03*

	Human Behavior and Performance, and Immunology.	*Charles/JSC (281-483-7224)*	

This document is the official current version of the Bioastronautics Critical Path Roadmap (BCPR). It has been reviewed by the Critical Path Control Panel (CPCP), and is endorsed by all members as indicated by the signature of the Chairperson (shown below). Any changes to the document must adhere to the policies and procedures outlined in the BCPR Charter (attached). This document will be issued on an annual basis to record changes to its content. The material contained in the companion BCPR Web Site will parallel this document.

The following BCPR items are under current configuration by the CPCP:

- **Taxonomy**
- **Discipline Areas**
- **Risks**
- **Risk Factors**
- **Critical Questions**
- **Risk Ranking and Risk Prioritization**
- **Critical Question Priorities**
- **Discipline Area Roadmaps**

_____ _____

John B. Charles, Ph.D. *Date*
CPCP Chairperson

Table of Contents

Tables and Figures

1.0 Introduction and Purpose

This document serves as the official baselined version of the Bioastronautics Critical Path Roadmap (BCPR). Developed by the Bioastronautics Office of the NASA Johnson Space Center in collaboration with the National Space Biomedical Research Institute (NSBRI), the BCPR is a systematic approach to the goal of reducing and managing risks to crew health, safety, and performance during, and following all human space flight missions. The BCPR offers a guide for the prioritization of research and technology efforts aimed toward that goal. It also provides a framework for assessing progress made toward mitigating specific risks as identified in the Bioastronautics Strategy and the Office of Biological and Physical Research (OBPR) Enterprise Strategy.

This document provides background information about the BCPR and presents its structure and content in detail. It has been reviewed by the Critical Path Control Panel (CPCP), and is endorsed by all members as indicated by the signature of the Chairperson (see p. 2). Any changes to this document must adhere to the policies and procedures outlined in the BCPR Charter (Appendix A-1). The document will be issued on an annual basis. The elements listed in this document, and any subsequent changes, will also be reflected in the companion BCPR web site (http://criticalpath.jsc.nasa.gov).

The following BCPR items are under current configuration control by the CPCP:

- Taxonomy[1]
- Discipline Areas
- Risks
- Risk Factors
- Critical Questions
- Risk Ranking (within discipline) and Risk Prioritization (across disciplines)
- Critical Question Priorities
- Discipline Area Roadmaps

2.0 BCPR Goals and Objectives

The Bioastronautics Strategy identifies three goals: reduce and manage risk; increase efficiency; and return benefits to Earth. The OBPR Enterprise Strategy for ensuring human survival in space has the primary outcome of ensuring the ability of humans to retain function and remain healthy and safe during and after

1 Taxonomy refers to the categories representing the structural elements of the CPR (i.e., risks, risk factors, critical questions, and deliverables) as well as to the individual research disciplines named in the 13 discipline areas. It is important to maintain a common taxonomy across all program elements involved in NASA's biomedical research and technology programs (e.g., the NASA HQs Office of Biological and Physical Sciences, the JSC Bioastronautics Program Office, and the NSBRI)

long-duration missions in and beyond low Earth orbit (LEO). Therefore, the goal of the BCPR is to enable, support and facilitate those ends.

The BCPR is a systematic approach for preventing or reducing the known risks to crew health, safety, and performance during and after long duration human space flight. Its objectives are to:

- Provide a guide for prioritization of research and technology.
- Assess progress toward effective and efficient risk mitigations by addressing and answering critical questions, identifying effective risk mitigation strategies, and adding any new risks and critical questions that are identified.
- Provide information for defining acceptable levels of identified risks

Key on-going activities are to:

- Include the scientific community in the process [e.g., informing them about the BCPR and ensuring that NASA Research Announcements (NRAs) reflect the most up-to-date BCPR information].
- Incorporate changes into the BCPR as new knowledge emerges about the risks, critical questions, countermeasures, and deliverables.
- Develop guidelines by which to quantify acceptable levels of risk.
- Continually assess and report on the congruence of the current and proposed Bioastronautics research and technology program with regard to BCPR.

3.0 Background

Since 1997, the NASA's lead center for the human elements of space flight, the Johnson Space Center, along with the National Space Biomedical Research Institute (NSBRI), NASA's partner in developing effective and efficient countermeasures, have worked to identify and assess the most critical risks to human safety, health and performance (Table 1) to be expected from mid- and far-term long duration human space flight missions (Table 2).

Table 1: BCPR Risks, Rank Order, Type and Discipline Area

ID[1]	Risk Title[2]	Rank[3]	Type[4]	Discipline Area[5]
1	Inability to Maintain Acceptable Atmosphere in Habitable Areas	1	II	Advanced Life Support (ALS)
2	Inability to Provide and Recover Potable Water	2	II	ALS
3	Inadequate Supplies (including maintenance, emergency provisions, and edible food)	2	II	ALS
4	Inability to Maintain Thermal Balance in Habitable Areas	3	II	ALS
5	Inability to Adequately Process Solid Wastes	3	II	ALS
6	Inadequate Stowage and Disposal Facilities for Solid and Liquid Trash Generated During Mission	4	II	ALS
7	Inadequate Nutrition (Malnutrition)	1	II	Food & Nutrition

8	Unsafe Food Systems	2	II	Food & Nutrition
9	Acceleration of Age-Related Osteoporosis	1	I	Bone Loss
10	Fracture & Impaired Fracture Healing	2	II	Bone Loss
11	Injury to Soft Connective Tissue, Joint Cartilage, & Intervertebral Disc Rupture w/ or w/o Neurological Complications	3	III	Bone Loss
12	Renal Stone Formation	4	III	Bone Loss
13	Occurrence of Serious Cardiac Dysrhythmias	1	II	Cardiovascular Alterations
14	Impaired Response to Orthostatic Stress	1	II	Cardiovascular Alterations
15	Diminished Cardiac Function	2	III	Cardiovascular Alterations
16	Manifestation of Previously Asymptomatic Cardiovascular Disease	3	III	Cardiovascular Alterations
17	Impaired Cardiovascular Response to Exercise Stress	4	III	Cardiovascular Alterations
18	Human Performance Failure Because of Poor Psychosocial Adaptation	1	I	Human Behavior & Performance
19	Human Performance Failure Because of Sleep and Circadian Rhythm Problems	2	II	Human Behavior & Performance
20	Human Performance Failure Because of Human System Interface Problems & Ineffective Habitat, Equipment, Design, Workload, or Inflight Information and Training Systems	3	III	Human Behavior & Performance
21	Human Performance Failure Because of Neurobehavioral Dysfunction	4	III	Human Behavior & Performance
22	Immunodeficiency/Infections	1	III	Immunology, Infection & Hematology
23	Carcinogenesis Caused by Immune System Changes	1	III	Immunology, Infection & Hematology
24	Altered Hemodynamic and Cardiovascular Dynamics caused by Altered Blood Components	1	III	Immunology, Infection & Hematology
25	Altered Wound Healing	2	III	Immunology, Infection & Hematology
26	Altered Host-Microbial Interactions	3	III	Immunology, Infection & Hematology
27	Allergies and Hypersensitivity Reactions	3	III	Immunology, Infection & Hematology

28	Loss of Skeletal Muscle Mass, Strength, and/or Endurance	1	II	Muscle Alterations & Atrophy
29	Inability to Adequately Perform Tasks Due to Motor Performance, Muscle Endurance, and Disruption in Structural and Functional Properties of Soft & Hard Connective Tissues of the Axial Skeleton	1	II	Muscle Alterations & Atrophy
30	Inability to Sustain Muscle Performance Levels to Meet Demands of Performing Activities of Varying Intensities	2	II	Muscle Alterations & Atrophy
31	Propensity to Develop Muscle Injury, Connective Tissue Dysfunction, and Bone Fractures Due to Deficiencies in Motor Skill, Muscle Strength and Muscular Fatigue	3	III	Muscle Alterations & Atrophy
32	Impact of Deficits in Skeletal Muscle Structure and Function on Other Systems	NR	III	Muscle Alterations & Atrophy
33	Disorientation and Inability to Perform Landing, Egress, or Other Physical Tasks, Especially During/After G-Level Changes (Acute spontaneous & provoked vertigo, nystagmus, oscillopsia, poor dynamic visual acuity)	1	II	Neurovestibular Adaptation
34	Impaired Neuromuscular Coordination and/or Strength (Gait ataxia, postural instability)	2	II	Neurovestibular Adaptation
35	Impaired Cognitive and/or Physical Performance Due to Motion Sickness Symptoms or Treatments, Especially During/After G-Level Changes (Including short term memory loss, reaction time increase, drowsiness, fatigue, torpor, irritability, ketosis)	3	III	Neurovestibular Adaptation
36	Vestibular Contribution to Cardioregulatory Dysfunction (Postlanding orthostatic intolerance, sleep and mood changes)	4	III	Neurovestibular Adaptation

37	Possible Chronic Impairment of Orientation or Balance Function Due to Microgravity or Radiation (Imbalance, gait ataxia, vertigo, chronic vestibular insufficiency, poor dynamic visual acuity)	5	III	Neurovestibular Adaptation
38	Carcinogenesis Caused by Radiation	1	I	Radiation Effects
39	Late Degenerative Tissue Effects including Non-Cancer Mortality, Cataracts, and Central Nervous System (CNS) Effects	2	II	Radiation Effects
40	Synergistic Effects from Exposure to Radiation, Microgravity and other Spacecraft Environmental Factors	3	II	Radiation Effects
41	Early or Acute Effects from Radiation Exposure	4	II	Radiation Effects
42	Radiation Effects on Fertility, Sterility, and Heredity	5	III	Radiation Effects
43	Trauma and Acute Medical Problems	1	I	Clinical Capabilities
44	Toxic Exposure	2	II	Clinical Capabilities
45	Altered Pharmacodynamics and Adverse Drug Reactions	3	II	Clinical Capabilities
46	Illness and Ambulatory Health Problems	4	III	Clinical Capabilities
47	Prevention, Development and Treatment of Space-Induced Decompression Sickness	5	III	Clinical Capabilities
48	Difficulty of Rehabilitation Following Landing	6	III	Clinical Capabilities
49	Post-landing Alterations in Various Systems Resulting in Severe Performance Decrements and Injuries	1	II	Multisystem (Cross Risk) Alterations
50	Allergies and Hypersensitivity Reactions from Exposure to the Enclosed Spacecraft & Other Environmental Factors	3	II	Environmental Health
51	Inability to Maintain Acceptable Atmosphere in Habitable Areas Due to Environmental Health Contaminants	1	II	Environmental Health
52	Inability to Provide and Recover Potable Water Due to Environmental Health Contaminants	2	II	Environmental Health
53	Inadequate Nutrition (Malnutrition) Due to Inability to Provide and Maintain a Bioregenerative System	3	II	ALS
54	Difficulty of Rehabilitation Following Landing Due to Nutritional Deficiencies	4	III	Food & Nutrition
55	Human Performance Failure Due to Nutritional Deficiencies	3	II	Food & Nutrition

1 Risk Identification number: Unique number assigned to each risk (1-55) used to track/identify each risk

2 Risk: The title of each risk

3 The Rank Order assigned to each risk by discipline experts in each Discipline Area; a Discipline Area may have more than 1 risk with the same risk ranking (risk order)

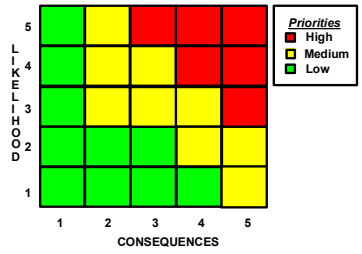
4 The Type assigned to each risk by experts; a risk may be Type I, Type II, or Type III depending upon the level of uncertainty regarding both knowledge of the risk itself (its occurrence and severity), and its mitigation status

5 The specific Discipline Area representing the risk; there are 12 Discipline Areas in the BCPR

The Critical Path Roadmap is incorporating a combination of standardized, quantitative and qualitative health, safety, and performance metrics, coupled with a risk communication tool widely used by Code M engineering and program management staff. This framework has been set out in the Bioastronautics Strategy. It defines an approach to involving representative stakeholders in defining the requirements of the human subsystem, developing a set of dependent measures to systematically monitor individual crewmembers before, during, and after space flight missions, and developing “5x5” charts to assess and communicate the evolving status of critical path risks. Examples of these charts are shown below.

Bioastronautics Risk Mitigation Definitions

LIKELIHOOD	What is the likelihood the risk will occur?		
	Level	Probability	. . . probability of occurrence . . .
	5	Very High	95 – 100%
	4	High	75 – 95%
	3	Moderate	25 – 75%
	2	Low	5 – 25%
	1	Very Low	0 – 5%



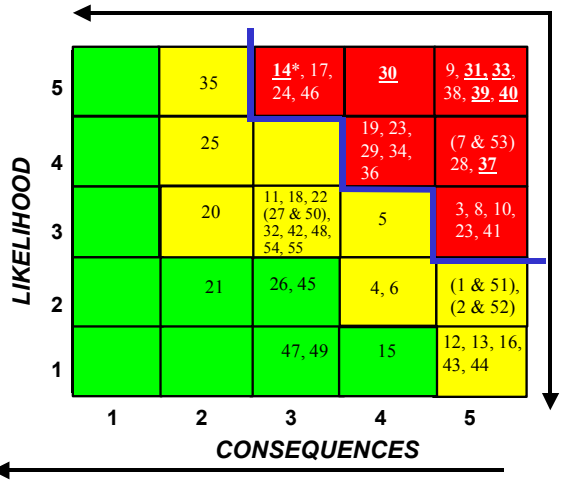
CONSEQUENCE	What is the worst case consequence (Crew or Mission) if the risk occurs with the current level of mitigation?					
	Level	1	2	3	4	5
	Crew Health, Safety, Performance	No impact to crew	Short- term, minor injury, illness, incapacitation, or impairment to crewmember	Serious injury, illness, incapacitation or impairment but not long term	Significant and long term impairment, but not permanent	Irreversible, catastrophic impairment, or death
	Mission Success	No impact to mission whatsoever; no loss of mission objectives	Relatively small impact to mission; loss limited to only a few of the mission objectives	Considerable impact and considerable loss of mission objectives	Significant mission impact; many mission objectives lost, however mission is not aborted	Significant mission impact; total loss of mission objectives; Mission aborted

1

Risk Reduction Strategy Based on *A Stabilize & Treat* Medical Model (Long Duration Exploration Class Missions)

Crew Health, Safety & Performance Requirements

Focused Research (Critical Questions)



Bioastronautics Top Risks

Score: 5 X 5
Risk # 9
Acceleration of Age-Related Osteoporosis

Score: 5 X 5
Risk # 31
Propensity to Develop Muscle Injury, Connective Tissue Dysfunction and Bone Fractures Due to Deficiencies in Motor Skill, Muscle Strength and Muscle Fatigue

Score: 5 X 5
Risk Number: 33
Distorientation & Inability to Perform Landing, Egress, Or Other Physical Tasks, Especially During/After G-level Changes

Score: 5 X 5
Risk # 38
Carcinogenesis Caused by Radiation

Score: 5 X 5
Risk Number: 39
Damage to Central Nervous System from Radiation Exposure

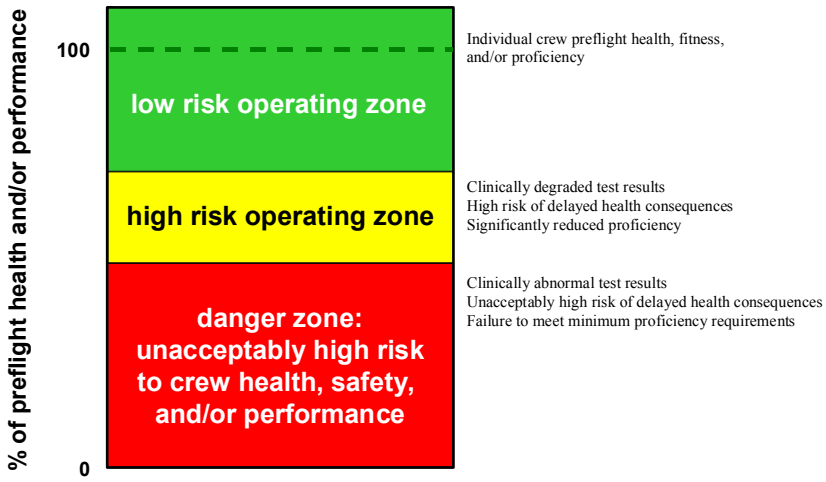
Score: 5 X 5
Risk Number: 40
Synergistic Effects from Exposure to Radiation, Microgravity and Other Spacecraft Environmental Factors

CHECS, Habitability & Other ISS Operational Programs

•Underline = *Long Lead Time Items*

2

Bioastronautics Risk Mitigation Effectiveness



3

Table 2. Design Reference Missions for planning purposes only (current as of July 2003).

Parameters	Human Mars Expedition (see Note 1)	International Space Station (see Note 2)	Lunar Exploration
Effective Date	*Not before 2025*	*Ongoing, 2 to 4 times/year*	*Not before 2018*
Out-bound Transit	*115-180 Days*	*Up to 1 year Duration*	*3-7 days*
Mars Surface Stay	*535-651 Days*		*4-30 days*
Return Transit	*130-180 Days*		*3-7 days*
No. of Transitions Between Gravity Fields	*Four:* *- 1 G* to 0 G* *- 0 G to 1/3 G* *- 1/3 G to 0 G* *- 0 G to 1G*	*Two:* *- 1 G to 0 G* *- 0 G to 1 G*	*Four:* *- 1 G* to 0 G* *- 0 G to 1/6 G* *- 1/6 G to 0 G* *- 0 G to 1G*
High G* Loading	*3 - 5 G (briefly) During Mars Aerobraking & Landing*	*3 G_x at Launch* *1.5 to 2 G_z at Landing*	*3 G_x at Launch* *1.5 to 2 G_z at Landing*
Crew Size	*6 (mixed nationalities and gender)*	*2-3 with growth potential to 6-7; mixed nationalities and gender*	*4-6 (mixed nationalities and gender)*

***G =** Gravity at Earth's surface

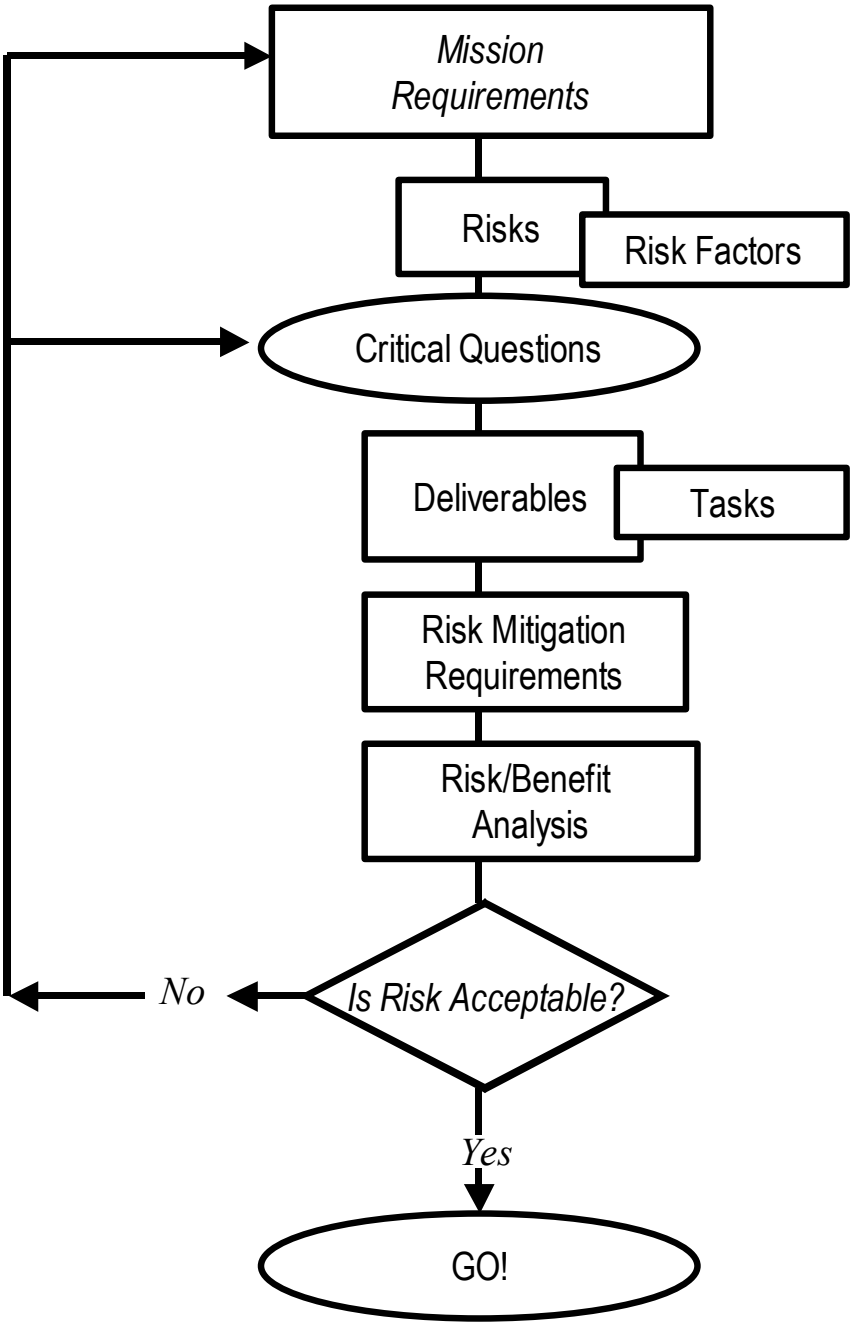
Note 1: For additional information related to the Mars Reference Mission, refer to the following web site: http://www-curator.jsc.nasa.gov/sn/PlanetaryMissions/EXLibrary/docs/MarsRef/contents.htm

Note 2: For additional information related to the International Space Station (ISS) refer to the following web site: http://spaceflight.nasa.gov/station/reference/index.html

4.0 Key Elements of the BCPR

The key elements of the BCPR and their interrelationships are shown in Figure 1. All elements are driven initially by the set of established mission requirements (see Table 1). The mission requirements set the context for the risks to be addressed by the research program and for establishing the acceptable levels of risk.

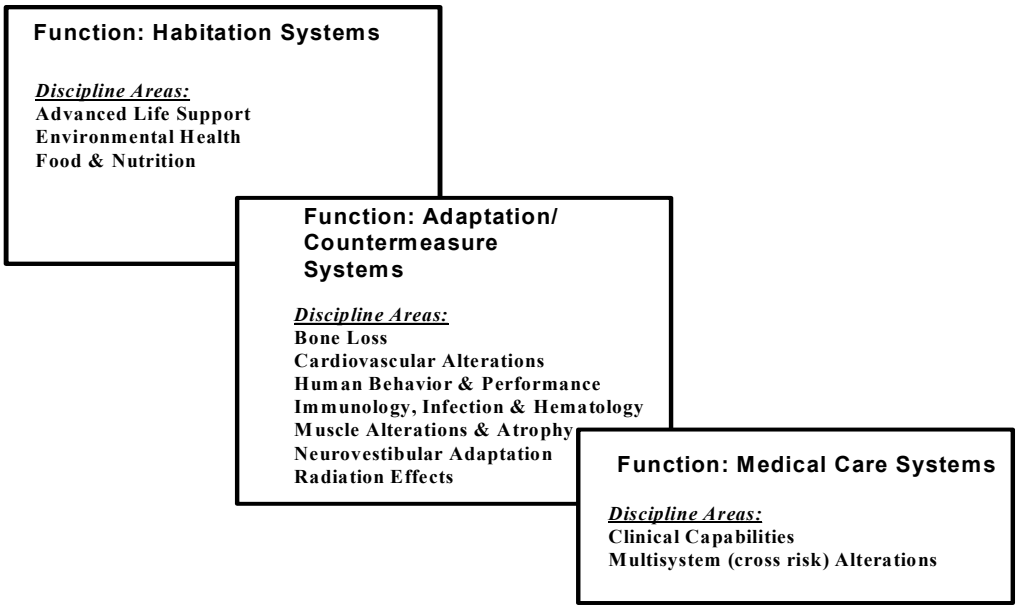
Figure 1. Key Elements of the Bioastronautics Critical Path Roadmap (BCPR)



4.1 Discipline Areas

The three major discipline areas in the BCPR are: Habitation Systems, Adaptation/Countermeasure Systems (including physiological and behavioral health), and Medical Care Systems. There are 12 discipline areas represented in the BCPR as shown in Figure 2.

Figure 2. BCPR Discipline Areas and Functional Systems



4.2 Risks

A risk is the occurrence of an adverse event from exposure to the space flight environment. It can include environmental hazards, contamination of the environment, adverse physiological adaptations, and medical trauma. Such exposure can result in dysfunctional physiological or behavioral adaptation that could lead to increased injuries, illness, or loss of life and/or mission objectives. Discipline experts identified the most critical risks in their respective areas, assessed each risk using a set of scoring criteria, and determined the rank order of all identified risks within their discipline.

4.2.1 Risk Scoring Criteria

Initially, a set of five criteria was developed to assess the significance and severity of each risk: the probability of occurrence of the risk without countermeasures; the probability of the occurrence of the risk with current countermeasures; the impact of the risk on crew health and performance; the impact of the risk on

accomplishment of mission objectives; and the overall status of the risk mitigation. The risk scoring criteria are detailed in Appendix A –1. (Note: these criteria are undergoing revision.)

4.2.2 Ranking of Risks

Each Discipline Area team rank-ordered the risks within their discipline using the risk scoring assessments and discussion among the team members. Teams could assign the same rank order to more than one risk.

4.2.3 Risk Prioritization

The following risks were identified by discipline experts as critical for (1) ensuring the health, safety, and performance of crewmembers during and after space flight and, (2) protecting the health of crews from any adverse biomedical effects initiated by space flight during their non-space flight career and retirement life. The risks have been prioritized to meet the requirements of a balanced human space flight program. A balanced program is defined as: multiple 180-day missions (plus extensions/ contingencies); STS 30-day missions; and those items that require long lead times to build human capability for extending beyond low Earth Orbit (LEO).

The following six categories represent the Bioastronautics Critical Path Roadmap (BCPR) risks prioritized for a balanced program. The prioritization corresponds to the Red/Yellow/Green 5X5 matrix of risk likelihood and consequences, with the addition of an assessment of the risk's current mitigation status, essentially ranging from none to complete. (Low risk mitigation status was defined as no mitigation available, or risk only partially mitigated and substantial research needed to lower the risk. High risk mitigation status was defined as either, mitigation available but not validated, or mitigation completed and understood.) As the Bioastronautics research program develops greater knowledge and certainty about the risks, and as the mitigation strategies are proven and validated, priorities will change.

Category 1. Red 1 – High Likelihood, High Consequence Risks with Low Risk Mitigation Status
Category 2. Red 2 – High Likelihood, High Consequence Risks with Higher Risk Mitigation Status
Category 3. Yellow 1 – High Likelihood/Moderate Consequence, or Moderate Likelihood/High Consequence Risks with Low Risk Mitigation Status
Category 4. Yellow 2 – High Likelihood/Moderate Consequence, or Moderate Likelihood/High Consequence Risks with Higher Risk Mitigation Status –
Category 5. Green1 – High Likelihood/Low Consequence Risks with Low Risk Mitigation Status
Category 6. Green2 – Low Likelihood/High Consequence Risks with Higher Risk Mitigation Status

Table 3. Bioastronautics Critical Path Risks Prioritized for a Balanced Program

Category 1: Red 1 – High Likelihood, High Consequence Risks with Low Risk Mitigation Status

ID[1]	Risk Title[2]	CPR Discipline Area[3]
18	Human Performance Failure Because of Poor Psychosocial Adaptation	Human Behavior & Performance
38 (23)	Carcinogenesis Caused by Radiation and by Immune System Changes	Radiation Effects / Immunology, Infection & Hematology
13	Occurrence of Serious Cardiac Dysrhythmias	Cardiovascular Alterations
33	Disorientation and Inability to Perform Landing, Egress, or Other Physical Tasks, Especially During/After G-Level Changes (Acute spontaneous & provoked vertigo, nystagmus, oscillopsia, poor dynamic visual acuity)	Neurovestibular Adaptation
39	Late Degenerative Tissue Effects including Non-Cancer Mortality, Cataracts, and Central Nervous System (CNS) Effects	Radiation Effects
40	Synergistic Effects from Exposure to Radiation, Microgravity and other Spacecraft Environmental Factors	Radiation Effects
43	Trauma and Acute Medical Problems	Clinical Capabilities

Category 2: Red 2 – High Likelihood, High Consequence Risks with Higher Risk Mitigation Status

ID[1]	Risk Title[2]	CPR Discipline Area[3]
9	Acceleration of Age-Related Osteoporosis	Bone Loss
19	Human Performance Failure Because of Sleep and Circadian Rhythm Problems	Human Behavior & Performance
46	Illness and Ambulatory Health Problems	Clinical Capabilities

Category 3: Yellow 1 – High Likelihood/Moderate Consequence, or Moderate Likelihood/High Consequence Risks with Low Risk Mitigation Status

ID[1]	Risk Title[2]	CPR Discipline Area[3]
1(51)	Inability to Maintain Acceptable Atmosphere in Habitable Areas	Advanced Life Support (ALS)
2 (52)	Inability to Provide and Recover Potable Water	ALS
5	Inability to Adequately Process Solid Wastes	ALS
8	Unsafe Food Systems	Food & Nutrition
11	Injury to Soft Connective Tissue, Joint Cartilage, & Intervertebral Disc Rupture w/ or w/o Neurological Complications	Bone Loss
16	Manifestation of Previously Asymptomatic Cardiovascular Disease	Cardiovascular Alterations
21	Human Performance Failure Because of Neurobehavioral Dysfunction	Human Behavior & Performance
28	Loss of Skeletal Muscle Mass, Strength, and/or Endurance	Muscle Alterations & Atrophy
29	Inability to Adequately Perform Tasks Due to Motor Performance, Muscle Endurance, and Disruption in Structural and Functional Properties of Soft & Hard Connective Tissues of the Axial Skeleton	Muscle Alterations & Atrophy
30	Inability to Sustain Muscle Performance Levels to Meet Demands of Performing Activities of Varying Intensities	Muscle Alterations & Atrophy
45	Altered Pharmacodynamics and Adverse Drug Reactions	Clinical Capabilities

Category 4: Yellow 2 – High Likelihood/Moderate Consequence, or Moderate Likelihood/High Consequence Risks with Higher Risk Mitigation Status

ID[1]	Risk Title[2]	CPR Discipline Area[3]
10	Fracture & Impaired Fracture Healing	Bone Loss
12	Renal Stone Formation	Bone Loss
14	Impaired Response to Orthostatic Stress	Cardiovascular Alterations
17	Impaired Cardiovascular Response to Exercise Stress	Cardiovascular Alterations
7 (53)	Inadequate Nutrition (Malnutrition)	Food & Nutrition
55	Human Performance Failure Due to Nutritional Deficiencies	Food & Nutrition
31	Propensity to Develop Muscle Injury, Connective Tissue Dysfunction, and Bone Fractures Due to Deficiencies in Motor Skill, Muscle Strength and Muscular Fatigue	Muscle Alterations & Atrophy
34	Impaired Neuromuscular Coordination and/or Strength (Gait ataxia, postural instability)	Neurovestibular Adaptation
36	Vestibular Contribution to Cardioregulatory Dysfunction (Postlanding OI, sleep and mood changes)	Neurovestibular Adaptation
41	Early or Acute Effects from Radiation Exposure	Radiation Effects
42	Radiation Effects on Fertility, Sterility, and Heredity	Radiation Effects
22	Immunodeficiency/Infections	Immunology, Infection & Hematology
24	Altered Hemodynamic and Cardiovascular Dynamics caused by Altered Blood Components	Immunology, Infection & Hematology
35	Impaired Cognitive and/or Physical Performance Due to Motion Sickness Symptoms or Treatments, Especially During/After G-Level Changes (Including short term memory loss, reaction time increase, drowsiness, fatigue, torpor, irritability, ketosis)	Neurovestibular Adaptation
44	Toxic Exposure	Clinical Capabilities
47	Prevention, Development and Treatment of Space-Induced Decompression Sickness	Clinical Capabilities
48 (54)	Difficulty of Rehabilitation Following Landing	Clinical Capabilities
49	Post-landing Alterations in Various Systems Resulting in Severe Performance Decrements and Injuries	Multisystem (Cross Risk) Alterations

Category 5: Green 1 – High Likelihood/Low Consequence or Low Likelihood/Moderate Consequence Risks with Low Risk Mitigation Status

ID[1]	Risk Title[2]	CPR Discipline Area[3]
3	Inadequate Supplies (including maintenance, emergency provisions, and edible food)	ALS
4	Inability to Maintain Thermal Balance in Habitable Areas	ALS
20	Human Performance Failure Because of Human System Interface Problems & Ineffective Habitat, Equipment, Design, Workload, or Inflight Information and Training Systems	Human Behavior & Performance
25	Altered Wound Healing	Immunology, Infection & Hematology
32	Impact of Deficits in Skeletal Muscle Structure and Function on Other Systems	Muscle Alterations & Atrophy
37	Possible Chronic Impairment of Orientation or Balance Function Due to Microgravity or Radiation (Imbalance, gait ataxia, vertigo, chronic vestibular insufficiency, poor dynamic visual acuity)	Neurovestibular Adaptation

Category 6: Green 2 – High Likelihood/Low Consequence or Low Likelihood/Moderate Consequence Risks with Higher Risk Mitigation Status

ID[1]	Risk Title[2]	CPR Discipline Area[3]
6	Inadequate Stowage and Disposal Facilities for Solid and Liquid Trash Generated During Mission	ALS
15	Diminished Cardiac Function	Cardiovascular Alterations
27 (50)	Allergies and Hypersensitivity Reactions	Immunology, Infection & Hematology
26	Altered Host-Microbial Interactions	Immunology, Infection & Hematology

1 Risk Identification number: Unique number assigned to each risk (1-55) used to track/identify each risk

2 Risk: The title of each risk

3 The specific Discipline Area representing the risk; there are 12 Discipline Areas in the BCPR

Historical Background: Risk Type (Cross-Risk Categorization)

An initial categorization was developed to classify different "types" of risks, based upon the relative importance of risk, in terms of what is known about the risk and its mitigation. It is presented here for reference during the transition to the more rigorous classification scheme described in section

As shown in Table 3a, risks were classified as Type I, Type II, Type III, and Type IV. A Type I risk represented a known and demonstrated serious problem without a proven countermeasure. A Type II risk was a suspected or demonstrated problem but without a mitigation validated in ground-based studies. A Type III risk was a demonstrated or suspected problem with a mitigation that is further formulated, developed or proven by ground-based testing but not yet verified in space flight. Type IV risks were clinically manageable risks with validated (effective and operational) countermeasures or risk mitigations. This document does not deal further with Type IV risks.

Table 3a. Assignment of Risk Type

	Known and Demonstrated Serious Problem	Suspected Serious Problem	Demonstrated Problem	Suspected Problem
No Countermeasure (CM) Concept	I	II	II or III	III
CM Concept *- No Ground Validation*	II	II	II or III	III
CM Concept *- No Space Verification*	III	III	III	III
Effective & Operational CM	*IV*	*IV*	*IV*	*IV*

4.3 Risk Factors

Risk factors represent conditions which increase the probability of occurrence of the risk and which may operate singly or in combination to contribute to the risk's

occurrence. Each risk has a set of risk factors (including, but not limited to, stress, diet, gender, and age) that may be common to more than one risk.

4.4 Critical Questions

Each risk has a set of critical questions that have been identified and prioritized by the Discipline Area teams in terms of their relative importance for addressing the specific risk. Critical questions encompass the key research and technology issues that must be addressed to understand and mitigate the risk. The Discipline Area teams identified the set of critical questions from review of previous NASA advisory committee reports and recent results from NASA's Bioastronautics research program. Questions address issues involving risk assessment and acceptability, underlying mechanisms and processes, countermeasure development and validation, and medical diagnosis and treatment. Questions may address more than risk. An important objective of the BCPR is to determine how well a critical question has been addressed, as a way to track progress toward risk reduction and management.

4.4 Deliverables

Deliverables represent the specific end-items that should be identified and completed through the research program. BCPR deliverables include (but are not limited to) the following: scientific knowledge about underlying mechanisms; risk characterization and assessment; countermeasure protocols, strategies, or procedures for risk reduction; or technology development. These are detailed in Table 3.

Table 4. Examples of BCPR Deliverables

(1)	Risk Characterization and Assessment
	Monitoring (physiological, behavioral, environmental)
	Modeling
(2)	Scientific Knowledge
	Mechanisms
	Processes
	Modeling
(3)	Development of Requirements
	Pharmacological
	Nutritional/Dietary
	Exercise Regimes and Fitness Levels
	Stress Reduction Strategies
(4)	Medical Capabilities
	Diagnosis and Treatment
	Post-landing Rehabilitation
(5)	Crew Screening and Selection Criteria
	Physiological, Genetic, Psychological
	Individual and Group
(6)	Crew Training (pre-, in-, and post-flight)
	Expert Systems
(7)	Design Specifications
	Artificial Gravity
	Habitation (lighting, noise, hygiene, food galley, etc.)
	Mechanical Devices
(8)	Mission Operations
	Monitoring (physiological, behavioral, environmental)

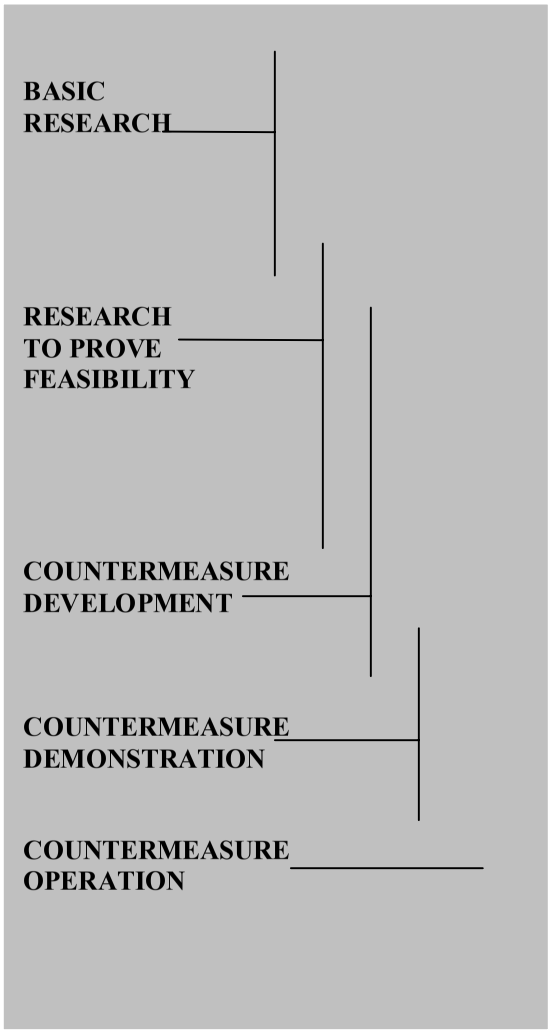
4.4.1 Readiness Levels

Readiness refers to the level of maturity of the countermeasure or technology being addressed by a task or project; it can be used also at the level of a specific deliverable. There are two methods used to determine level of readiness. Both instruments are used to determine the readiness levels of the individual BCPR tasks and their deliverables:

- The Countermeasure Readiness Levels (CRL) instrument (Figure 3) begins with basic research to test and validate hypotheses (Levels 1 - 3), moves through formulation of countermeasure concepts, initial demonstration of efficacy (Levels 4 – 5), to clinical trials/testing (Levels 6 – 7), and finally, validation and operational implementation (Levels 8 – 9).
- The Technology Readiness Levels (TRL) instrument (Figure 4) has been used widely by NASA's technology programs to measure the stage of maturity of a specific technology under development. TRL are based also on nine levels ranging from relatively immature and untested concepts to

fully developed, flight validated and operationally proven systems or components.

Figure 3. Countermeasure Readiness Levels (CRL)



Level	Definition
1.	PHENOMENON OBSERVED AND REPORTED. PROBLEM DEFINED.
2.	HYPOTHESIS FORMED, PRELIMINARY STUDIES TO DEFINE PARAMETERS. DEMONSTRATE FEASIBILITY.
3.	VALDIDATED HYPOTHESIS. UNDERSTANDING OF SCIENTIFIC PROCESSES UNDERLYING PROBLEM.
4.	FORMULATION OF COUNTERMEASURES CONCEPT BASED ON UNDERSTANDING OF PHENOMENON.
5.	PROOF OF CONCEPT TESTING AND INITIAL DEMONSTRATION OF FEASIBILITY AND EFFICACY.
6.	LABORATORY/CLINICAL TESTING OF POTENTIAL COUNTERMEASURE IN SUBJECTS TO DEMONSTRANT EFFICACY OF CONCEPT.
7.	EVALUATION WITH HUMAN SUBJECTS IN CONTROLLED LABORATORY SIMULATING OPERATIONAL SPACEFLIGHT ENVIRONMENT.
8.	VALIDATION WITH HUMAN SUBJECTS IN ACTUAL OPERATIONAL SPACE FLIGHT TO DEMONSTRATE EFFICACY AND OPERATIONAL FEASIBILITY.
9.	COUNTERMEASURE FULLY FLIGHT TESTED AND READY FOR IMPLEMENTATION.

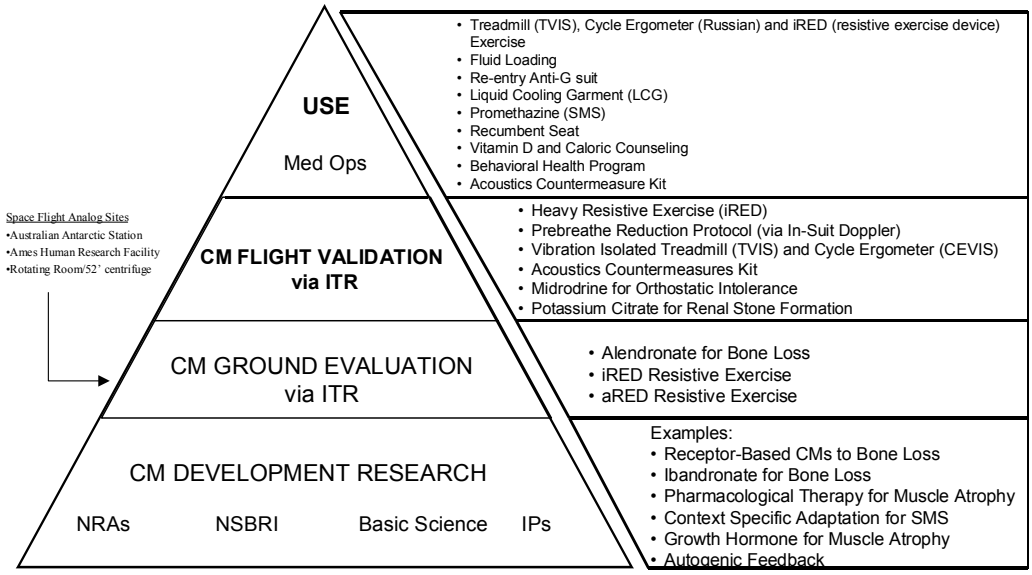
Figure 4. Technology Readiness Levels (TRL)

Level	Definition
TRL1	Basic principles observed
TRL2	Technology concept and/or application formulated
TRL3	Analytical and experimental critical function/proof-of-concept
TRL4	Component and/or breadboard validation in lab
TRL5	Component and/or breadboard in relevant environment
TRL6	System/subsystem model or prototype demonstration in relevant environment
TRL7	Subsystem prototype in a space environment
TRL8	System completed and flight qualified through demonstration
TRL9	System flight proven through mission operations

To support NASA's ISS and long duration human exploration objectives, the Countermeasure Evaluation and Validation Project (CEVP) has been established. The CEVP will serve as the final element in the process in which ideas and concepts emerging from basic research are developed into operational countermeasures (see Figure 5).

Figure 5. Countermeasure (CM) Life Cycle

ISS NASA Countermeasures



4.5 Risk Mitigation Requirements

A risk mitigation requirement is the statement of the requirement to be imposed upon the operational flight or hardware system by a BCPR deliverable after it has been tested, validated and completed. Each implemented countermeasure should appear as a flight rule or a Bioastronautics requirement.

4.6 Risk/Benefit Analysis

Once risks have been identified, characterized and prioritized, a decision making process evaluates a range of options and selects an outcome or course of action. This step may be referred to as risk or cost/benefit analysis, and is important in resource allocation decisions. The knowledge of what is needed to better understand and mitigate the risk, to what level of acceptability, or enhanced efficiency, the maturity of the mitigation or deliverable, mission parameters and other resources such as crew time, power and space, are part of the decision making process.

5.0 CPR Approach and Results

Informed decisions about risk reduction options are the combination of two interacting processes – analysis and deliberation. While there are no set rules on how to achieve the right balance, both are necessary to reduce risk. The BCPR was based on an iterative process that incorporated review, analysis, and deliberations throughout the process.

5.1 Risk Identification and Characterization

Currently there are 55 critical risks and 250 unique critical questions (See Table 4). There was no requirement for each discipline area to have the same number of risks and critical questions. Risk Data Sheets, including risk description, risk factors, critical questions, and key references for each risk are presented in Appendix A-2.

Table 5. Summary Number of Risks and Critical Questions for Each Discipline Area

Discipline Area	Number of Risks	Number of Critical Questions (Total)	Number of Critical Questions (Unique)
Advanced Life Support	7	40	40
Bone Loss	4	34	23
Cardiovascular Alterations	5	20	20
Environmental Health	3	26	13
Food & Nutrition	4	27	18
Human Behavior & Performance	4	22	21
Immunology, Infection & Hematology	6	47	30
Muscle Alterations & Atrophy	5	15	9
Neurovestibular Adaptation	5	29	21
Radiation Effects	5	40	13
Clinical Capabilities	6	47	39
Multisystem (Cross Risk) Alterations	1	3	3
Totals	**55**	**343**	**250**

The following section contains separate tables for the risks in each of the 12 discipline areas. For tracking purposes, each risk was assigned a risk identification number that appears in the first column of each table. The risk title is the name of the risk, as currently maintained. Risk factors associated with each risk are listed in each of the tables. Risk rank within the discipline is also shown. Risks are listed by rank order.

6.0 BCPR Risks Categorized by Discipline Area

6.1 Advanced Life Support

Risk ID No.[1]	Risk Title[2]	Risk Factors[3]	Risk Rank[4]	Risk Priority[5]
1	Inability to Maintain Acceptable Atmosphere in Habitable Areas	Remoteness, Crew health/susceptibility to degree of system closure	1	Yellow 1
53	Inadequate Nutrition (Malnutrition) Due to Inability to Provide and Maintain a Bioregenerative System	Not specified	1	Yellow 2
2	Inability to Provide and Recover Potable Water	Remoteness, Crew health/susceptibility to degree of system closure	2	Yellow 1
3	Inadequate Supplies (including maintenance, emergency provisions, and edible food)	Not specified	2	Green 1
4	Inability to Maintain Thermal Balance in Habitable Areas	Sources of heat from other elements of the mission; Orientation of the vehicle during flight; Orientation of vehicle and/or habitat on planetary surface; Location on planetary surface; Planetary environment (temperature ranges & extremes, dust, seasonal variations, etc.); Use or availability of local planetary resources	3	Green 1
5	Inability to Adequately Process Solid Wastes	Not specified	3	Yellow 1
6	Inadequate Stowage and Disposal Facilities for Solid and Liquid Trash Generated During Mission	Not specified	4	Green 2

6.2 Bone Loss

Risk ID No.[1]	Risk Title[2]	Risk Factors[3]	Risk Rank[4]	Risk Priority[5]
9	Acceleration of Age-Related Osteoporosis	Age; Recovery rate postflight; Gender; Baseline BMD; Diet	1	Red 2
10	Fracture and Impaired Fracture Healing	Poor nutrition; Decreased muscle mass; Muscle/bone strength imbalance; Endocrine dysfunction	2	Yellow 2
11	Injury to Soft Connective Tissue, Joint Cartilage, & Intervertebral Disc Rupture w/ or w/o Neurological Complications	Decreased muscle strength; Decreased loads on muscle and connective tissue; Muscle atrophy and bone/mineral loss; Biomechanical disturbances	3	Yellow 1
12	Renal Stone Formation	Inflight overloaded schedule, motion sickness on return to 1 g, decreased skeletal loads inflight, hypercalcuria risk throughout flight, decreased urine volume, increased bone resorption	4	Yellow 2

4 The unique number assigned to each risk to track the risk

5 The name of each risk

6 The list of risk factors associated with each risk

7 The assigned rank of the risk within the Discipline Area as determined by expert analysis and deliberations

8 Classification of a risk into one of three categories across discipline area as determined through expert analysis and deliberations

6.3 Cardiovascular Alterations

Risk ID No.[1]	Risk Title[2]	Risk Factors[3]	Risk Rank[4]	Risk Priority[5]
13	Occurrence of Serious Cardiac Dysrhythmias	Fluid and Electrolyte Imbalance; Diminished Cardiac Mass	1	Red 1
14	Impaired Cardiovascular Response to Orthostatic Stress	Plasma fluid shift; Fluid intake; Altered hemodynamic regulation; Changes in vascular compliance	1	Yellow 2
15	Diminished Cardiac Function	Reduction of stress on heart over prolonged period in weightlessness	2	Green 2
16	Manifestation of Previously Asymptomatic Cardiovascular Disease	Lack of sufficiently sensitive screening measures	3	Yellow 1
17	Impaired Cardiovascular Response to Exercise Stress	Diminished Cardiac Function; Decreased blood volume	4	Yellow 2

6.4 Environmental Health

Risk ID No.[1]	Risk Title[2]	Risk Factors[3]	Risk Rank[4]	Risk Priority[5]
51	Inability to Maintain Acceptable Atmosphere in Habitable Areas Due to Environmental Health Contaminants	Remoteness; Crew health/susceptibility to degree of system closure	1	Yellow 1
52	Inability to Provide and Recover Potable Water Due to Environmental Health Contaminants	Remoteness; Crew health/susceptibility to degree of system closure	2	Yellow 1
50	Allergies and Hypersensitivity Reactions from Exposure to the Enclosed Spacecraft & Other Environmental Factors	Chemically sensitive individuals or altered immune responses; Impaired pulmonary capacity	3	Green 2

6.5 Food and Nutrition

Risk ID No.[1]	Risk Title[2]	Risk Factors[3]	Risk Rank[4]	Risk Priority[5]
7	Inadequate Nutrition (Malnutrition)	Inadequate nutritional requirements; Inability to provide food; Improper food intake; Stress; Countermeasure induced-alterations in nutrient requirements	1	Yellow 2
8	Unsafe Food Systems	Chemical or microbial contamination; Packaging; Environmental control	2	Yellow 1
55	Human Performance Failure Due to Nutritional Deficiencies	Malnutrition; Inadequate nutrition requirements; Stress; Boredom	3	Yellow 2
54	Difficulty of Rehabilitation Following Landing Due to Nutritional Deficiencies	Bone loss; Renal disease; Infectious disease; Radiation biochemical changes; Muscle wasting; Decreased red blood cell mass	4	Yellow 2

1 The unique number assigned to each risk to track the risk

2 The name of each risk

3 The list of risk factors associated with each risk

4 The assigned rank of the risk within the Discipline Area as determined by expert analysis and deliberations

5 Classification of a risk into one of three categories across Discipline Areas as determined through expert analysis and deliberations

6.6 Human Behavior and Performance

Risk ID No.[1]	Risk Title[2]	Risk Factors[3]	Risk Rank[4]	Risk Priority[5]
18	Human Performance Failure Because of Poor Psychosocial Adaptation	Psychosocial Adaptation	1	Red 1
19	Human Performance Failure Because of Sleep and Circadian Rhythm Problems	Sleep and Circadian Rhythms	2	Red 2
20	Human Performance Failure Because of Human System Interface Problems & Ineffective Habitat, Equipment, Design, Workload, or Inflight Information and Training Systems	Human-Systems Interface; Habitability; Information Management and Training	3	Green 1
21	Human Performance Failure Because of Neurobehavioral Dysfunction	Behavioral Health	4	Yellow 1

6.7 Immunology, Infection and Hematology

Risk ID No.[1]	Risk Title[2]	Risk Factors[3]	Risk Rank[4]	Risk Priority[5]
22	Immunodeficiency/Infections	Stress; Radiation exposure; Decreased cell function; Altered environmental exposure	1	Yellow 2
23	Carcinogenesis Caused by Immune System Changes	Radiation exposure; Chemical exposure; Viruses	1	Red 1
24	Altered Hemodynamic and Cardiovascular Dynamics caused by Altered Blood Components	Loss of plasma and red blood cells due to exposure to microgravity	1	Yellow 2
25	Altered Wound Healing	Not specified	2	Green 1
26	Altered Host-Microbial Interactions	Spacecraft environmental factors; Host defense factors; Nutrition	3	Green 2
27	Allergies and Hypersensitivity Reactions	Exposure to environmental agents (chemical/biological); Autoimmune disease	3	Green 2

1 The unique number assigned to each risk to track the risk

2 The name of each risk

3 The list of risk factors associated with each risk

4 The assigned rank of the risk within the Discipline Area as determined by expert analysis and deliberations

5 Classification of a risk into one of three categories across Discipline Areas as determined through expert analysis and deliberations

6.8 Muscle Alterations and Atrophy

Risk ID No.[1]	Risk Title[2]	Risk Factors[3]	Risk Rank[4]	Risk [5]
28	Loss of Skeletal Muscle Mass, Strength, and/or Endurance	Muscle atrophy; Decrease in muscle strength and muscle endurance; Altered motor performance; Altered muscle phenotype; Nutritional deficiencies (decreased carbohydrates); and Hormonal imbalance (circadian changes, dysregulation)	1	Yellow 1
29	Inability to Adequately Perform Tasks Due to Motor Performance, Muscle Endurance, and Disruption in Structural and Functional Properties of Soft & Hard Connective Tissues of the Axial Skeleton	Muscle atrophy; Decrease in muscle strength and muscle endurance; Altered motor performance; Altered muscle phenotype; Nutritional deficiencies (decreased carbohydrates); and Hormonal imbalance (circadian changes, dysregulation)	1	Yellow 1
30	Inability to Sustain Muscle Performance Levels to Meet Demands of Performing Activities of Varying Intensities	Muscle atrophy; Decrease in muscle strength and muscle endurance; Altered motor performance; Altered muscle phenotype; Nutritional deficiencies (decreased carbohydrates); and Hormonal imbalance (circadian changes, dysregulation)	2	Yellow 1
31	Propensity to Develop Muscle Injury, Connective Tissue Dysfunction, and Bone Fractures Due to Deficiencies in Motor Skill, Muscle Strength and Muscular Fatigue	Muscle atrophy; Decrease in muscle strength and muscle endurance; Altered motor performance	3	Yellow 2
32	Impact of Deficits in Skeletal Muscle Structure and Function on Other Systems	Muscle atrophy; Decrease in muscle strength and muscle endurance; Altered motor performance; Altered muscle phenotype; Nutritional deficiencies (decreased carbohydrates); and Hormonal imbalance (circadian changes, dysregulation)	NR*	Green 1

*NR: Not rated by discipline area team

1 The unique number assigned to each risk to track the risk

2 The name of each risk

3 The list of risk factors associated with each risk

4 The assigned rank of the risk within the discipline area as determined by expert analysis and deliberations

5 Classification of a risk into one of three categories across discipline areas as determined through expert analysis and deliberations

6.9 Neurovestibular Adaptation

Risk ID No.[1]	Risk Title[2]	Risk Factors[3]	Risk Rank[4]	Risk Priority[5]
33	Disorientation and Inability to Perform Landing, Egress, or Other Physical Tasks, Especially During/After G-Level Changes (Acute spontaneous & provoked vertigo, nystagmus, oscillopsia, poor dynamic visual acuity)	Sleep disorders; Sleep disruption; Circadian dysrhythmia; Impaired cognitive or psychomotor performance; Space motion sickness	1	Red 1
34	Impaired Neuromuscular Coordination and/or Strength (Gait ataxia, postural instability)	Acute or intermittent exposure to 0-G, Re-exposure to 1-G or reentry/landing accelerations, Head movements about any axis, Walking or running after landing, Ambiguous or misleading visual cues for spatial orientation; Coriolis effects in rotating environments, Vomiting; exacerbated by post flight orthostatic hypotension and/or muscular deconditioning.	2	Yellow 2
35	Impaired Cognitive and/or Physical Performance Due to Motion Sickness Symptoms or Treatments, Especially During/After G-Level Changes (Including short term memory loss, reaction time increase, drowsiness, fatigue, torpor, irritability, ketosis)	Change in gravity levels; head and body movements; walking or running after landing; ambiguous or misleading spatial cues causing disorientation; Coriolis effects in rotating environments. Factors that enhance space motion sickness symptoms including post flight orthostatic hypotension, increased environmental temperature, unpleasant odors, etc. Impaired cognitive function due to sleep deprivation or circadian dysrhythmia.	3	Yellow 2
36	Vestibular Contribution to Cardioregulatory Dysfunction (Postlanding orthostatic intolerance, sleep and mood changes)	Return to 1 G	4	Yellow 2
37	Possible Chronic Impairment of Orientation or Balance Function Due to Microgravity or Radiation (Imbalance, gait ataxia, vertigo, chronic vestibular insufficiency, poor dynamic visual acuity)	Radiation exposure; Prolonged exposure to microgravity	5	Green 1

1 The unique number assigned to each risk to track the risk

2 The name of each risk

3 The list of risk factors associated with each risk

4 The assigned rank of the risk within the Discipline Area as determined by expert analysis and deliberations

5 Classification of a risk into one of three categories across Discipline Areas as determined through expert analysis and deliberations

6.10 Radiation Effects

Risk ID No.[1]	Risk Title[2]	Risk Factors[3]	Risk Rank[4]	Risk Priority[5]
38	Carcinogenesis Caused by Radiation	Genetic susceptibility; Nutrition; Immune function; Growth factors; Stress; Environmental mutagens; Age; Gender	1	Red 1
39	Late Degenerative Tissue Effects including Non-Cancer Mortality, Cataracts, and Central Nervous System (CNS) Effects	Genetic susceptibility; Extracellular milieu; Environmental toxic agents	2	Red 1
40	Synergistic Effects from Exposure to Radiation, Microgravity and other Spacecraft Environmental Factors	Microgravity or weightlessness; Genetic susceptibility; Environmental cytotoxic and mutagenic compounds	3	Red 1
41	Early or Acute Effects from Radiation Exposure	Genetic susceptibility; Stress; Immune function; Environmental toxic agents	4	Yellow 2
42	Radiation Effects on Fertility, Sterility, and Heredity	Genetic susceptibility; Age; Gender; Environmental toxic agents	5	Yellow 2

6.11 Clinical Capabilities

Risk ID No.[1]	Risk Title[2]	Risk Factors[3]	Risk Rank[4]	Risk Priority[5]
43	Trauma and Acute Medical Problems	Prolonged exposure to microgravity and transitions to altered gravity levels upon landing on planetary surfaces; Isolated and confined environment; Highly autonomous operations with delayed communications	1	Red 1
44	Toxic Exposure	Enclosed spacecraft; Chemical leak; Increased or altered sensitivity of individuals to environmental agents; Allergies; Stress; Changes in immune system response; Inadequate ALS; Prolonged dwelling in an enclosed environment	2	Yellow 2
45	Altered Pharmacodynamics and Adverse Drug Reactions	Polypharmacy (multidrug administration); Idiosyncratic tendencies; Allergies; Pharmocotherapeutic changes in microgravity (e.g., adsorption changes metabolism; Drug effect changes-SMS)	3	Yellow 2
46	Illness and Ambulatory Health Problems	Prolonged exposure to microgravity and transitions to altered gravity levels upon landing on planetary surfaces; Isolated and confined environment; Highly autonomous operations with delayed communications	4	Red 2
47	Prevention and Treatment of Decompression Sickness in NASA Operations	Deconditioning, Improper EVA operations, Musculoskeletal pain due to bends	5	Yellow 2
48	Difficulty of Rehabilitation Following Landing	Reentry into higher gravitational forces; Fluid loading; Exercise; Fitness; G-suit; Deconditioning; Impaired response to orthostatic stress; Vestibular contributions to cardioregulatory dysfunction; Possible chronic impairment of balance function; Muscle performance; Endurance or strength impairment	6	Yellow 2

1 The unique number assigned to each risk to track the risk

2 The name of each risk

3 The list of risk factors associated with each risk

4 The assigned rank of the risk within the Discipline Area as determined by expert analysis and deliberations

5 Classification of a risk into one of three categories across Discipline Areas as determined through expert analysis and deliberations

6.12 Multisystem (Cross Risk) Alterations

Risk ID No.[1]	Risk Title[2]	Risk Factors[3]	Risk Rank[4]	Risk Priority[5]
49	Post-landing Alterations in Various Systems Resulting in Severe Performance Decrements and Injuries	Reentry into higher gravitational forces; Fluid loading; Exercise; Fitness; G-suit; Deconditioning; Impaired response to orthostatic stress; Vestibular contributions to cardioregulatory dysfunction; Possible chronic impairment of balance function; Muscle performance; Endurance or strength impairment; Prolonged exposure to microgravity and transitions to altered gravity levels upon landing on planetary surfaces; isolated and confined environment; highly autonomous operations with delayed communications	1	Yellow 2

1 The unique number assigned to each risk to track the risk

2 The name of each risk

3 The list of risk factors associated with each risk

4 The assigned rank of the risk within the Discipline Area as determined by expert analysis and deliberations

5 Classification of a risk into one of three categories across Discipline Areas as determined through expert analysis and deliberations

7.0 Risks, Critical Questions, Question Priorities and Categories

Each risk has a set of critical questions that must be addressed in order to mitigate the risk. Each question was prioritized by the Discipline Area experts in terms of its relative importance for addressing and mitigating the risk. The priority score is based on a 1 – 4 scale; "1" represents highest priority and "4" relatively lower priority. In addition, each question was categorized in terms of the type of research or technology effort it represents (i.e., assessment, mechanisms, countermeasures, or medical diagnosis and treatment). These categories relate to deliverables as well. The following section presents the critical question information for each of the 55 risks by the 12 discipline areas. (The key for the information contained in the tables is presented at the end of the each discipline area section.)

7.1 Advanced Life Support

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Inability to Maintain Acceptable Atmosphere in Habitable Areas (Risk No. 1)	1.01	What is the best method for controlling total atmospheric pressure, O2 and CO2 partial pressure?	2	Countermeasures
	1.02	What is the best CO2 adsorbing material and/or mechanism?	2	Countermeasures
	1.03	What is the best way to recover the O2 from the CO2?	2	Countermeasures
	1.04	What is the best way to control trace contaminants?	2	Countermeasures
	1.05	Are sensors available to provide environmental data?	3	Countermeasures
	1.06	Are sensors available to monitor performance?	3	Countermeasures
	1.07	What is the best monitoring and control system?	3	Countermeasures
Inability to Provide and Recover Potable Water (Risk No. 2)	1.16	What is the best method for supplying potable water to use points?	3	Countermeasures
	1.17	What waste water collection and transport mechanisms are best?	3	Countermeasures
	1.18	What methods are best for removal of organic and inorganic contaminants in waste water (physicochemical, biological)?	2	Countermeasures
	1.19	What is the best method to add a residual biocide?	3	Countermeasures
	1.20	What is the best way to store and maintain potability of recycled water?	2	Countermeasures
	1.21	What methods (sensors) are available to measure water quality parameters?	3	Countermeasures
	1.22	What is the best monitoring and control system?	3	Countermeasures
Inadequate Supplies(including maintenance, emergency provisions, and edible food) (Risk No. 3)	1.45	What storm shelter supplies must be provided to allow the crew to survive radiation threats requiring retreat into safe areas for prolonged time periods?	3	Countermeasures

7.1 Advanced Life Support (continued)

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Inability to Maintain Thermal Balance in Habitable Areas (Risk No. 4)	1.23	What is the best thermal working fluid for the thermal control components in habitable areas?	3	Countermeasures
	1.24	What materials and designs are best used to acquire waste heat (condensing heat exchangers, cold plates, etc.)?	3	Countermeasures
	1.25	What material and designs are best for the thermal transport components (pumps, phase separators, etc.)?	3	Countermeasures
	1.26	What materials and designs are best for the thermal rejection components (radiators for use on vehicles vs moon and Mars)?	2	Countermeasures
	1.27	What is the best way to control humidity?	3	Countermeasures
	1.28	Are sensors available to provide environmental data?	3	Countermeasures
	1.29	Are sensors available to monitor performance of the thermal system?	3	Countermeasures
	1.30	What is the best monitoring and control system?	3	Countermeasures
Inability to Adequately Process Solid Wastes (Risk No. 5)	1.31	What is the best method to process solid wastes for storage and/or disposal?	2	Countermeasures
	1.32	What is the best method to process solid wastes to recover resources?	2	Countermeasures
	1.33	What constraints should be imposed on materials such as packaging, paper, etc.?	3	Countermeasures
	1.34	How should solid waste streams be separated (edible plant biomass, trash and paper, feces, etc.)?	3	Countermeasures
	1.35	What is the best methodology for dealing with residuals?	2	Countermeasures
	1.36	Are sensors available to monitor performance?	3	Countermeasures
	1.37	What is the best monitoring and control system?	3	Countermeasures
Inadequate Stowage and Disposal Facilities for Solid and Liquid Trash Generated During Mission (Risk No. 6)	1.44	Could any of the solid waste be recycled in such a way to provide building material for habitability features needed in subsequent phases of the mission?	3	Countermeasures

7.1 Advanced Life Support (continued)

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Inadequate Nutrition (Malnutrition) Due to Inability to Provide and Maintain a Bioregenerative System (Risk No. 53)	1.46	What percentage of crew food needs should be attributed to ALS plant products?	1	Countermeasures
	1.47	What processing processes and hardware will be required to convert ALS plant products into edible supplements to stowed food?	1	Countermeasures
	1.15	What are the effects of radiation on plant growth?	1	Mechanisms
	1.09	What is the best method to grow plants with established plant production requirements including light, water, gas, gas composition and pressure, trace gas contaminants, nutrient status, mechanical support, freedom from diseases and insects?	2	Countermeasures
	1.10	What species and cultivars should be used to optimize production and meet nutritional requirements?	2	Mechanisms
	1.11	What mechanized or automated systems for planting, harvesting, and monitoring and control are required?	2	Countermeasures
	1.12	What methods are best to maintain genetic integrity?	2	Countermeasures
	1.14	What processing and storage of plant products must be accommodated?	2	Countermeasures
	1.13	What are the interfaces with the air revitalization and water recovery systems?	3	Countermeasures

1 Risk – Title of risk and assigned risk identification number

2 CQ No.: Assigned unique critical question identification number to track each question; first digit represents the discipline area (1-12); next two digits represent sequential number s for the questions addressing the risk

3 Critical Question: The statement of the critical question

4 Priority: The priority score of the question based on expert opinion, of the relative importance of the question for addressing/mitigating the risk; a score of "1" represents highest priority, "4" lower priority

5 Critical Question Category: The assigned category of the question in terms of the type of research or technology effort it represents (i.e., risk assessment/acceptability, underlying mechanisms/processes, countermeasures/ mitigation, medical diagnosis and treatment)

7.2 Bone Loss

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Acceleration of Age-Related Osteoporosis (Risk No. 9)	2.03	Will bone mass loss (e.g., 1-1.5% per month) continue unabated for missions greater than six months in duration, or will it eventually plateau at some time consistent with absolute bone mineral density? Is this "minimum BMD" site-specific or consistent over numerous skeletal sites?	1	Risk Assessment
	2.09	What are the most important predictors for bone loss during prolonged exposure to hypogravity, especially with reference to ethnicity, gender, age, baseline BMD, bone morphometry (e.g., femoral neck length)?	1	Risk Assessment
	2.19	Is bone loss reversible and within what time frame: Can geometry and architecture return to baseline as well as BMD?	1	Risk Assessment
	2.25	Can the pattern of reversibility be correlated with serum or urine biomarkers of bone turnover?	3	Mechanisms
	2.26	What treatment regimen in returning crew with bone loss will most effectively restore bone mass, geometry and strength to their preflight integrity?	2	Countermeasures
	2.20	What is the most optimal rehabilitation regimen upon return to normal gravity to maximize return to baseline BMD and bone morphometry, especially given that muscle strength will recover more quickly than will bone strength?	2	Countermeasures

*NR: Currently not rated by the discipline area team

7.2 Bone Loss (Continued)

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	CQ & RM/ CM Category[5]
Fracture and Impaired Fracture Healing (Risk No. 10)	2.03	Will bone mass loss (e.g., 1-1.5%) continue unabated for missions greater than six months in duration, or will it eventually plateau at some time consistent with absolute bone mineral density? Is this "minimum BMD" site-specific or consistent over numerous skeletal sites?	2	Risk Assessment
	2.01	What is the relative risk of sustaining a traumatic and/or stress fracture for a given decrement in bone mineral density or bone geometry in an astronaut-equivalent population (i.e., 30-60 year old health men and women) who are also physically active?	1	Risk Assessment
	2.09	What are the most important predictors for bone loss during prolonged exposure to hypogravity, especially with reference to ethnicity, gender, age, baseline BMD, bone morphometry (e.g., femoral neck length)?	1	Risk Assessment
	2.11a	Does prolonged exposure to hypogravity lead to impaired healing of fractures?	1	Risk Assessment
	2.11b	Does prolonged exposure to hypogravity result in changes in structural or functional integrity of vertebral bone?	2	Risk Assessment
	2.24	Which animal models will be most effective in defining the risk of fracture and impaired healing of fractures with prolonged exposure to microgravity?	2	Mechanisms
	2.02	What are the mechanical loads imposed on important skeletal sites in the Martian environment of 1/3 g, given anticipated work tasks?	1	Mechanisms
	2.04	What localized bone changes at tendon sites would contribute to increased risk of avulsion fractures (i.e., how much disparity between bone & muscle strength can be incurred without increased risk of avulsion fracture)?	2	Mechanisms
	2.05	Is there an additive or synergistic effect of estrogen deficiency (as in post-menopausal or amenorrheic women) and prolonged exposure to hypogravity?	4	Mechanisms
	2.10	Does hypogravity exposure change the nutritional requirements for optimal bone health (e.g., does calcium absorption decrease)?	1	Mechanisms
	2.12	What are the signal transduction pathways allowing bone cells to sense gravity and loading on bone?	2	Mechanisms
	2.13	Does hypogravity affect the size, viability or differentiation of precursor bone cell populations?	2	Mechanisms
	2.15	Are there important other mechanisms for bone loss with hypogravity that are critical to developing effective countermeasures (e.g., fluid shifts with altered hydrostatic pressure, changes in blood flow, immune system alterations)?	2	Mechanisms
	2.06	What pharmacological agents will most effectively minimize the decrease in bone mass with hypogravity? Are anabolic as well as anti-resorptive agents required?	1	Countermeasures
	2.07	What are the specifics of the optimal exercise regimen to be followed during exposure to hypogravity to minimize decreases in bone mass with regard to workout duration, intensity, frequency? Is impact loading an essential element? If so, how can it be produced in hypogravity?	1	Countermeasures
	2.08	Is there an optimal combination of exercise (an anabolic stimulus) and a pharmacological countermeasure (anti-resorptive) to minimize decrements in bone mass in hypogravity?	1	Countermeasures
	2.26	What treatment regimen in returning crew with bone loss will most effectively restore bone mass, geometry and strength to their preflight integrity?	2	Countermeasures
	2.14	What practical diagnostic tools can be utilized during multi-year missions to monitor and quantify changes in bone mass and strength (e.g., biochemical markers, DEXA, ultrasound)?	2	Medical Diagnosis & Treatment

*NR: Currently not rated by the discipline area team

7.2 Bone Loss (Continued)

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Injury to Soft Connective Tissue, Joint Cartilage, Intervertebral Disc Rupture with or without Neurological Complications (Risk No. 11)	2.17	What is the incidence of soft connective tissue injury and pain during recovery after prolonged hypogravity or bed rest? (Use pre- and post flight analyses of MRI scan of spine and extremities and post flight follow-up studies over six months to one year.)	1	Risk Assessment
	2.18	What countermeasures can reduce the incidence of soft connective tissue injury and pain during recovery after prolonged hypogravity or bed rest?	1	Countermeasures
Renal Stone Formation (Risk No. 12)	2.05	Is there an additive or synergistic effect of estrogen deficiency (as in post-menopausal or amenorrheic women) and prolonged exposure to hypogravity?	4	Mechanisms
	2.09	What are the most important predictors for bone loss during prolonged exposure to hypogravity, especially with reference to ethnicity, gender, age, baseline BMD, bone morphometry (e.g., femoral neck length)?	1	Mechanisms
	2.10	Does hypogravity exposure change the nutritional requirements for optimal bone health (e.g., does calcium absorption decrease)?	1	Mechanisms
	2.13	Does hypogravity affect the size, viability or differentiation of precursor bone cell populations?	2	Mechanisms
	2.06	What pharmacological agents will most effectively minimize the decrease in bone mass with hypogravity? Are anabolic regimes as well as anti-resorptive agents required?	1	Countermeasures
	2.07	What are the specifics of the optimal exercise regimen to be followed during exposure to hypogravity to minimize decreases in bone mass with regard to workout duration, intensity, frequency? Is impact loading an essential element? If so, how can this be produced in hypogravity?	1	Countermeasures
	2.08	Is there an optimal combination of exercise (an anabolic stimulus) and a pharmacological countermeasure (anti-resorptive) to minimize decrements in bone mass in hypogravity?	1	Countermeasures
	2.21	Does existing data allow prediction of stone risk?	3	Risk Assessment

1 Risk – Title of risk and assigned risk identification number

2 CQ No.: Assigned unique critical question identification number to track each question; first digit represents the discipline area (1-12); next two digits represent sequential numbers for the questions addressing the risk

3 Critical Question: The statement of the critical question

4 Priority: The priority score of the question based on expert opinion, of the relative importance of the question for addressing/mitigating the risk; a score of "1" represents highest priority, "4" lower priority

5 Critical Question Category: The assigned category of the question in terms of the type of research or technology effort it represents (i.e., risk assessment/acceptability, underlying mechanisms/processes, countermeasures/ mitigation, medical diagnosis and treatment)

7.3 Cardiovascular Alterations

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Occurrence of Serious Cardiac Dysrhythmias (Risk No. 13)	3.01	Does spaceflight increase susceptibility to serious cardiac dysrhythmias and, if so, what are the mechanisms?	1	Risk Assessment/ Mechanisms
	3.02	Can risk of serious cardiac dysrhythmias be predicted for individual crewmembers?	1	Risk Assessment/ Mechanisms
	3.03	What countermeasures may prevent or reduce the occurrence of serious cardiac dysrhythmias during long term spaceflight?	2	Countermeasures
	3.04	Can serious cardiac dysrhythmias be effectively diagnosed and treated during spaceflight?	2	Medical Diagnosis and Treatment
Impaired Cardiovascular Response to Orthostatic Stress (Risk No. 14)	3.05	What are the physiological and environmental factors by which spaceflight decreases orthostatic tolerance?	1	Mechanisms
	3.06	How does duration of spaceflight affect the severity and time course of orthostatic intolerance, and what are the mechanisms?	1	Risk Assessment/ Mechanisms
	3.07	Is orthostatic intolerance likely to develop on the surface of Mars?	1	Risk Assessment
	3.08	Can spaceflight-induced orthostatic intolerance be predicted for individual crewmembers?	1	Risk Assessment/ Countermeasures
	3.09	What countermeasures can be developed to overcome or prevent orthostatic intolerance?	1	Countermeasures
Diminished Cardiac Function (Risk No. 15)	3.17	Does long duration spaceflight lead to diminished cardiac function and, if so, what are the mechanisms and is the process reversible?	2	Mechanisms
	3.18	What is the extent of reduction in cardiac mass associated with long duration spaceflight and what are the mechanisms?	2	Mechanisms
	3.19	Can susceptibility to reduced cardiac function be predicted for individual crewmembers?	2	Risk Assessment/ Countermeasures
	3.20	What countermeasures may be effective in mitigating the risk?	2	Countermeasures

7.3 Cardiovascular Alterations (Continued)

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Manifestation of Previously Asymptomatic Cardiovascular Disease (Risk No. 16)	3.14	Are cardiovascular diseases likely to be aggravated by spaceflight and, if so, which ones and by what mechanisms?	1	Risk Assessment/ Mechanisms
	3.15	What improved screening methods might identify crewmembers with underlying cardiovascular disease which may be aggravated by spaceflight?	1	Countermeasures
	3.16	What countermeasures may be effective in mitigating the risk?	2	Countermeasures
Impaired Cardiovascular Response to Exercise Stress (Risk No. 17)	3.10	What are the physiological and environmental factors by which spaceflight decreases aerobic exercise capacity?	1	Mechanisms
	3.11	How does duration of spaceflight affect the severity of limitation of exercise capacity?	1	Risk Assessment
	3.12	Can aerobic exercise capacity limitation be predicted for individual crewmembers?	2	Countermeasures
	3.13	What countermeasures can be developed to overcome aerobic exercise capacity limitation?	2	Countermeasures

1 Risk – Title of risk and assigned risk identification number

2 CQ No.: Assigned unique critical question identification number to track each question; first digit represents the discipline area (1-12); next two digits represent sequential number s for the questions addressing the risk

3 Critical Question: The statement of the critical question

4 Priority: The priority score of the question based on expert opinion, of the relative importance of the question for addressing/mitigating the risk; a score of "1" represents highest priority, "4" lower priority

5 Critical Question Category: The assigned category of the question in terms of the type of research or technology effort it represents (i.e., risk assessment/acceptability, underlying mechanisms/processes, countermeasures/ mitigation, medical diagnosis and treatment)

7.4 Environmental Health

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Allergies and Hypersensitivity Reactions from Exposure to the Enclosed Spacecraft and Other Environmental Factors (Risk No. 50)	4.07	What impact do spaceflight-induced biological, physiological, & immunological changes have on the susceptibility of crewmembers to toxic substances in the air and water?	2	Mechanisms/ Countermeasures
	4.08	What are the effects of exposure to ultrafine and larger (respirable and non-respirable) particles (e.g., Martian dust) on crew health, safety and performance?	2	Risk Assessment
	4.14	How will persons who are hypersensitive to chemicals and microbes in air and water be identified?	2	Countermeasures
	4.16	If hypersensitivity develops during spaceflight, how will individuals be treated?	1	Medical Diagnosis & Treatment
Inability to Maintain Acceptable Atmosphere in Habitable Areas Due to Environmental Health Contaminants (Risk No. 51)	4.01	What are the most likely sources of severe air or water pollution and how can these sources be controlled over long periods of time?	1	Risk Assessment & Countermeasures
	4.02	What are the acceptable numbers and kinds of microorganisms in air, water, food, and surfaces?	1	Risk Assessment
	4.03	What resources are required to manage plausible environmental risks during long and remote missions?	1	Countermeasures
	4.04	How can traditional limited-time exposure and human toxicological data be used to predict acceptable values for inhalation and ingestion exposures to single chemicals and/or to mixtures?	2	Risk Assessment
	4.05	What approaches to setting exposure standards may be used when insufficient data are available to allow prediction of acceptable exposure levels?	1	Risk Assessment
	4.06	How much risk do materials that condense inside the spacecraft pose to the environmental health?	2	Risk Assessment
	4.07	What impact do spaceflight-induced biological, physiological, & immunological changes have on the susceptibility of crewmembers to toxic substances in the air and water?	2	Mechanisms
	4.08	What are the effects of exposure to ultrafine and larger (respirable and non-respirable) particles (e.g., Martian dust) on crew health, safety and performance?	2	Risk Assessment
	4.11	What are the interactions of microbes, chemicals, and plants in a CELSS on air and water quality?	2	Mechanisms
	4.12	What are the effects of the space environment on microbial interactions with space systems and humans?	2	Mechanisms
	4.13	How rapidly can acceptable air quality be recovered after a severe pollution condition and what is the effect on humidity condensate and the water recovery system?	2	Countermeasures
	4.15	How can automated real-time systems be used to monitor air and water quality for a Mars mission, and how will the crew interpret results without ground support?	1	Risk Assessment / Countermeasures

7.4 Environmental Health (Continued)

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Inability to Provide and Recover Potable Water due to Environmental Health Contaminants (Risk No. 52)	4.01	What are the most likely sources of severe air or water pollution and how can these sources be controlled over long periods of time?	1	Risk Assessment & Countermeasures
	4.02	What are the acceptable numbers and kinds of microorganisms in air, water, food, and surfaces?	1	Risk Assessment
	4.03	What resources are required to manage plausible environmental risks during long and remote missions?	1	Countermeasures
	4.04	How can traditional limited-time exposure and human toxicological data be used to predict acceptable values for inhalation and ingestion exposures to single chemicals and/or to mixtures?	2	Risk Assessment
	4.05	What approaches to setting exposure standards may be used when insufficient data are available to allow prediction of acceptable exposure levels?	2	Risk Assessment
	4.07	What impact do spaceflight-induced biological, physiological, & immunological changes have on the susceptibility of crewmembers to toxic substances in the air and water?	2	Mechanisms
	4.11	What are the interactions of microbes, chemicals, and plants in a CELSS on air and water quality?	2	Mechanisms
	4.12	What are the effects of the space environment on microbial interactions with space systems and humans?	2	Mechanisms
	4.13	How rapidly can acceptable air quality be recovered after a severe pollution condition and what is the effect on humidity condensate and the water recovery system?	2	Mechanisms/ Countermeasures
	4.15	How can automated real-time systems be used to monitor air and water quality for a Mars mission, and how will the crew interpret results without ground support?	1	Countermeasures

1 Risk – Title of risk and assigned risk identification number

2 CQ No.: Assigned unique critical question identification number to track each question; first digit represents the discipline area (1-12); next two digits represent sequential numbers for the questions addressing the risk

3 Critical Question: The statement of the critical question

4 Priority: The priority score of the question based on expert opinion, of the relative importance of the question for addressing/mitigating the risk; a score of "1" represents highest priority, "4" lower priority

5 Critical Question Category: The assigned category of the question in terms of the type of research or technology effort it represents (i.e., risk assessment/acceptability, underlying mechanisms/processes, countermeasures/ mitigation, medical diagnosis and treatment)

7.5 Food and Nutrition

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Inadequate Nutrition (Malnutrition) (Risk No. 7)	5.03	What are the nutritional requirements for exploration missions, e.g., calories, protein, calcium, iron, antioxidants, iodine, vitamin D, electrolytes?	1	Countermeasures
	5.04	What are the potential impacts of countermeasures on nutritional requirements?	1	Mechanisms
	5.05	What are the psychosocial requirements of the food system?	2	Mechanisms
	5.08	What technology will be required to develop a viable food system?	2	Countermeasures
	5.09	What type(s) of food system(s) should be used?	1	Countermeasures
	5.07	What monitoring method should be used to assure food safety during the entire mission?	2	Countermeasures
	5.10	What are the means of monitoring nutritional status during the mission?	3	Countermeasures
	5.01	How much flight access is required to answer above questions?	2	NA
	5.06	What are the sensory changes (taste, odor, etc.) that occur during spaceflight?	4	Mechanisms
	5.02	What are the impacts of changing gravity on the food system i.e., galley?	3	Mechanisms
Unsafe Food Systems (Risk No. 8)	5.13	What are the effects of extended space travel on the sensory and nutrient properties of food?	2	Mechanisms
	5.08	What technology will be required to develop a viable food system?	1	Countermeasures
	5.09	What type(s) of food system(s) should be used?	1	Countermeasures
	5.07	What monitoring method should be used to assure food safety during the entire mission?	2	Countermeasures
	5.02	What are the impacts of changing gravity on the food system i.e., galley?	3	Mechanisms / Processes

7.5 Food and Nutrition (Continued)

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Unsafe Food Systems (Risk No. 8)	5.11	What type of packaging is required?	1	Countermeasures
	5.12	What is the risk of chemical and microbial contamination?	1	Risk Assessment
	5.01	How much flight access is required to answer above questions?	4	NA
Human Performance Failure Due to Nutritional Deficiencies (Risk No. 55)	5.03	What are the nutritional requirements for exploration missions (e.g., calories, protein, calcium, iron, antioxidants, iodine, vitamin D, electrolytes)?	1	Countermeasures
	5.14	What is an acceptable food system?	2	Countermeasures
	5.01	How much flight access is required to answer above questions?	3	NA
	5.05	What are the psychosocial requirements of the food system?	2	Mechanisms/ Processes / Countermeasures
Difficulty of Rehabilitation Following Landing Due to Nutritional Deficiencies (Risk No. 54)	5.03	What are the nutritional requirements for exploration missions, e.g. calories, protein, calcium, iron, antioxidants, iodine, vitamin D, electrolytes?	1	Countermeasures
	5.15	What are the decrements in nutritional status due to long term spaceflight?	1	Risk Assessment
	5.16	What monitoring (biochemical, anthropometric, clinical assessments) during rehabilitation is required?	3	Medical Diagnosis and Treatment
	5.17	What level of dietary counseling is needed for crewmembers during rehabilitation?	3	Countermeasures
	5.18	Are there inflight countermeasures that affect nutritional status (promote or cause decrements)?	2	Countermeasures

1 Risk – Title of risk and assigned risk identification number

2 CQ No.: Assigned unique critical question identification number to track each question; first digit represents the discipline area (1-12); next two digits represent sequential numbers for the questions addressing the risk

3 Critical Question: The statement of the critical question

4 Priority: The priority score of the question based on expert opinion, of the relative importance of the question for addressing/mitigating the risk; a score of "1" represents highest priority, "4" lower priority

5 Critical Question Category: The assigned category of the question in terms of the type of research or technology effort it represents (i.e., risk assessment/acceptability, underlying mechanisms/processes, countermeasures/ mitigation, medical diagnosis and treatment)

7.6 Human Behavior and Performance

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Human Performance Failure Because of Poor Psychosocial Adaptation (Risk No. 18)	6.01	What are the fundamental behavioral and social stressors during long duration missions that will most likely affect crew performance, both individual and team?	1	Risk Assessment
	6.02	What factors contribute to the breakdown of individual and team performance, and team coordination with mission support with regard to scheduling, prioritization of work activities and control of timelines?	1	Risk Assessment
	6.03	What behaviors, experiences, personality traits, and leadership styles in crewmembers most contribute to optimal performance? How are these factors related to team performance?	2	Mechanisms/ Processes
	6.04	What crewmember behaviors, experiences, personality traits, and leadership styles that optimize performance can be identified during the selection process and be used to select and assemble the best teams for long duration missions?	2	Countermeasures
	6.17	What are the systems of knowledge, psychosocial support methods, attitudes, and behavior towards mission operations used by agency management, ground controllers, crewmembers and their families? How do these systems influence individual and group performance and behavior?	2	Countermeasures
Human Behavior Failure Because of Sleep and Circadian Rhythm Problems (Risk No. 19)	6.05	What are the acute and long term effects of exposure to the space environment on biological rhythmicity on sleep architecture, quality and quantity, and their relationship to performance capability?	1	Mechanisms/ Processes
	6.06	Which countermeasure or combination of behavioral and physiological countermeasures will optimally mitigate specific performance problems associated with sleep loss and circadian disturbances during a Mars mission?	1	Countermeasures
	6.07	What are the long term effects of countermeasures employed to mitigate performance problems with sleep loss and circadian disturbances during a Mars mission?	2	Mechanisms/ Processes
	6.08	What are the best methods of inflight monitoring the status of sleep and circadian functioning and for assessing the effects of sleep loss and circadian dysrhythmia on performance capability that are also portable and non-intrusive in the spaceflight environment?	2	Medical Diagnosis & Treatment
	6.10	What workload schedule(s) per workday will best enhance crew performance and mitigate adverse effects of the space environment?	2	Countermeasures
	6.21	What mathematical and experimental models best predict performance problems associated with sleep-wake and work history and circadian rhythm status, and also provide guidelines for successful countermeasure strategies?	2	Countermeasures
	6.18	What individual and behavioral characteristics will best predict successful adaptation to long term spaceflight of sleep and circadian physiology and the neurobehavioral performance functions they regulate?	NR*	Risk Assessment/ Mechanisms/Processes

7.6 Human Behavior and Performance

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & CM Category[5]
Human Performance Failure Because of Human System Interface Problems and Ineffective Habitat, Equipment Design, Workload, or Inflight Information and Training Systems (Risk No. 20)	6.09	What information systems, resource management methods and tools, and communications systems architecture(s) and equipment will best support the crew's ability to operate autonomously, exchange information, learn and maintain proficiency on critical tasks, and meet the objectives of a Mars mission? How will artificial intelligence and automation be used to enable crew autonomy?	1	Countermeasures
	6.10	What workload schedule(s) per workday will best enhance crew performance and mitigate adverse effects of the space environment?	2	Countermeasures
	6.11	What methods of assessing human performance capabilities will be most effective and useable during a Mars mission?	2	Medical Diagnosis & Treatment
	6.12	What factors in systems and habitat design will best enhance the crew's ability to live and work in the space environment? How are these factors different from shorter duration missions?	2	Mechanisms/ Processes
	6.22	What theoretical, analytical and computational models of human performance best predict changes in human performance capabilities and characteristics in the context of a Mars mission, and enable designing and evaluating systems, procedures, and interface designs to mitigate negative changes in performance capabilities?	1	Risk Assessment / Countermeasures / Risk Mitigation
Human Performance Failure Because of Neurobehavioral Dysfunction (Risk No. 21)	6.13	What model(s) of behavioral health and task performance best predict problems and provide guidelines for effective treatment of illness (e.g., Depression, Anxiety, Trauma, Psychiatric Dysfunction)?	2	Risk Assessment
	6.14	What are the best countermeasures for rapidly recognizing and rapidly managing neurobehavioral dysfunction, emotional and stress-related dysfunction, neuropsychiatric dysfunction, and social psychological dysfunction and how does the spaceflight environment affect their implementation?	2	Countermeasures
	6.15	What are the acute and long term effects of exposure to the space environment on the human cognition and performance capabilities, including processes of sensation and perception, learning, vigilance, cognition, problem-solving, decision making, and motor skills, and how do such changes affect human performance capabilities and behavior?	1	Mechanisms/ Processes
	6.16	What are the acute and long term effects of exposure to the space environment (microgravity, isolation, stress) on the nervous system (at the cellular, molecular, or organismic levels) and on related neurobehavioral mechanisms, including neurobiology related to behavior and mood regulation?	2	Mechanisms/ Processes
	6.19	What are the acute and long term effects of exposure to the space environment on human emotion and psychological responses, including emotional reactivity, stress responses, long term modulation of mood, and vulnerability to affective disorders?	3	Mechanisms/ Processes
	6.20	What are the best methods of inflight recognition, monitoring, and management of neurobehavioral dysfunction, including cognitive and performance dysfunction, emotional and stress-related dysfunction, neuropsychiatric dysfunction, and social psychological dysfunction?	1	Medical Diagnosis & Treatment

1 Risk – Title of risk and assigned risk identification number

2 CQ No.: Assigned unique critical question identification number to track each question; first digit represents the discipline area (1-12); next two digits represent sequential numbers for the questions addressing the risk

3 Critical Question: The statement of the critical question

4 Priority: The priority score of the question based on expert opinion, of the relative importance of the question for addressing/mitigating the risk; a score of "1" represents highest priority, "4" lower priority

5 Critical Question Category: The assigned category of the question in terms of the type of research or technology effort it represents (i.e., risk assessment/acceptability, underlying mechanisms/processes, countermeasures/ mitigation, medical diagnosis and treatment)

*NR: Currently not rated by the discipline area team

7.7 Immunology, Infection and Hematology

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Immunodeficiency/ Infections (Risk No. 22)	7.17	Which potentially infectious agents will crewmembers be exposed to and what are their sources?	2	Risk Assessment
	7.01	Are there assays of immune function that reliably predict immune compromise?	2	Risk Assessment
	7.29	Are there surrogate marker assays that can be adapted to space travel that will quantitate the degree of immunodeficiency for antibody, T-cell, phagocyte, and complement function?	1	Risk Assessment / Medical Diagnosis & Treatment
	7.22	Are there countermeasures for spaceflight-associated defects in antibody, T-cell, phagocyte, and compliment systems?	1	Countermeasures
	7.23	Are there countermeasures for infections developed in space travel, especially latent virus infections?	1	Countermeasures
	7.13	What diagnostic and environmental monitoring laboratory technologies need to be developed for the detection and diagnosis of infectious disease in microgravity?	3	Medical Diagnosis and Treatment
	7.10	Does the change in fluid distribution away from the extremities affect microcirculation in peripheral tissues, and does this represent a risk to the crew (wound healing, lymphocyte migration, immune surveillance)?	1	Risk Assessment / Mechanisms
	7.03	Do factors associated with flight (stress, environment, microgravity, nutritional status, radiation) affect humoral or cell-mediated immune function, non-specific immunity, mucosal immunity, or immune surveillance capabilities of crewmembers in a manner that exposes them to unacceptable medical risk (disease, allergy, delayed wound healing)?	1	Risk Assessment / Mechanisms
	7.11	Does the spacecraft environment exert a selective pressure on environmental microorgansisms which presents the crew with increased health risks (e.g. heliobacteria and ulcers)?	2	Risk Assessment
	7.04	Do factors associated with spaceflight increase activation of latent viruses?	2	Risk Assessment / Mechanisms
	7.20	Does the loss of blood volume in spaceflight affect immune surveillance?	2	Risk Assessment / Mechanisms
	7.21	Does the altercation of sleep wake cycles produce alterations in chronobiology of immune responses due to upsetting the neuroendocrine axis and producing stress?	1	Mechanisms
	7.25	Are there deficiencies of diet or micronutrients in long term space travel that would negatively impact on the CD4* T-Cell population and produce immonosupression?	2	Mechanisms
	7.26	Are there diet supplements or additives that could restore a malnutrition-induced state of immunosuppression?	2	Countermeasures
	7.28	Do conditions of mechanical forces of space travel disrupt cytokine: cytokine receptor signal transmissions in immune cells?	2	Mechanisms

7.7 Immunology, Infection and Hematology (Continued)

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Carcinogenesis Caused by Immune System Changes (Risk No. 23)	7.14	What is the risk of cancer during or following long duration spaceflight?	1	Risk Assessment
	7.01	Are there assays of immune function that reliably predict immune compromise?	2	Risk Assessment
	7.29	Are there surrogate marker assays that can be adapted to space travel that will quantitate the degree of immunodeficiency for antibody, T-cell, phagocyte, and complement function?	1	Risk Assessment
	7.24	Are there countermeasures for development of malignancy in space travel?	1	Countermeasures
	7.18	What diagnostic and treatment capabilities are required for radiation induced illness?	3	Medical Diagnosis and Treatment
	7.30	Does the change in fluid distribution affect microcirculation in peripheral tissues, and does this alter lymphocyte migration or immune surveillance?	2	Mechanisms
	7.03	Do factors associated with flight (stress, environment, microgravity, nutritional status, radiation) affect humoral or cell-mediated immune function, mucosal immunity, non-specific immunity, or immune surveillance capabilities of crewmembers in a manner that exposes them to unacceptable medical risk (disease, allergy, delayed wound healing)?	1	Mechanisms
	7.04	Do factors associated with spaceflight increase reactivation of latent tumor viruses?	2	Mechanisms
	7.15	Which oncogenic mechanisms may be activated by in-flight radiation exposure?	2	Mechanisms
	7.21	Does the altercation of sleep wake cycles produce alterations in chronobiology of immune responses due to upsetting the neuroendocrine axis and producing stress?	1	Mechanisms

7.7 Immunology, Infection and Hematology (Continued)

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Altered Hemodynamic and Cardiovascular Dynamics Caused by Alterations in Blood Components (Risk No. 24)	7.12	Does the anemia following spaceflight diminish the aerobic capacity of individuals entering a gravitational environment or represent a risk to crewmembers on landing?	2	Risk Assessment
	7.03	Do factors associated with flight (stress, environment, microgravity, nutritional status, radiation) affect humoral or cell-mediated immune function, non-specific immunity, mucosal immunity, or immune surveillance capabilities of crewmembers in a manner that exposes them to unacceptable medical risk (disease, allergy, delayed wound healing)?	1	Risk Assessment
	7.31	Does the change in fluid distribution away from the extremities affect microcirculation in peripheral tissues, and does this represent a cardiovascular, muscle, or bone risk to the crew?	1	Mechanisms
	7.20	Does the loss of blood volume in spaceflight affect immune surveillance?	1	Mechanisms
	7.02	Can the physiologic mechanisms responsible for hematopoesis be influenced to increase red cell mass?	2	Mechanisms, Countermeasures
	7.29	Are there surrogate marker assays that can be adapted to space travel that will quantitate the degree of immunodeficiency for antibody, T-cell, phagocyte, and complement function?	1	Medical Diagnosis and Treatment
Altered Wound Healing (Risk No. 25)	7.01	Are there assays of immune function that reliably predict immune compromise?	2	Risk Assessment
	7.29	Are there surrogate marker assays that can be adapted to space travel that will quantitate the degree of immunodeficiency for antibody, T-cell, phagocyte, and complement function?	1	Risk Assessment, Medical Diagnosis & Treatment
	7.16	Which compounds can be used as effective promoters of wound healing?	3	Countermeasures
	7.32	Does the change in fluid distribution away from the extremities affect microcirculation in peripheral tissues, and does this represent a risk to the crew (wound healing, lymphocyte migration, immune surveillance)?	2	Risk Assessment / Mechanisms
	7.03	Do factors associated with flight (stress, environment, microgravity, nutritional status, radiation) affect humoral or cell-mediated immune function, mucosal immunity, non-specific immunity, or immune surveillance capabilities of crewmembers in a manner that exposes them to unacceptable medical risk (disease, allergy, delayed wound healing)?	1	Risk Assessment / Mechanisms

7.7 Immunology, Infection and Hematology (Continued)

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Altered Host-Microbial Interactions (Risk No. 26)	7.06	Does spaceflight alter microbial growth rates, mutation rates, or pathogenicity?	2	Risk Assessment, Mechanisms
	7.11	Does the spacecraft environment exert a selective pressure on environmental microorganisms which presents the crew with increased health risks (e.g., heliobacteria and ulcers)?	2	Risk Assessment, Mechanisms
	7.09	Does spaceflight alter the exchange of genetic material between microorganisms?	2	Mechanisms
	7.19	Does spaceflight alter host-microbe balance?	2	Mechanisms
	7.23	Are there countermeasures for infections developed in space travel, especially latent-virus infections?	1	Countermeasures
	7.13	What diagnostic and environmental monitoring laboratory technologies need to be developed for the detection and diagnosis of infections in microgravity?	3	Medical Diagnosis and Treatment
Allergies and Hypersensitivity Reactions (Risk No. 27)	7.01	Are there assays of immune function that reliably predict immune compromise?	3	Risk Assessment
	7.03	Do factors associated with flight (stress, environment, microgravity, nutritional status, radiation) affect humoral or cell-mediated immune function, mucosal immunity, non-specific immunity, or immune surveillance capabilities of crewmembers in a manner that exposes them to unacceptable medical risk (disease, allergy, delayed wound healing)?	1	Risk Assessment, Mechanisms
	7.05	Do unique environmental factors inside the spacecraft promote transmission of microbial pathogens, or cause increased risk of infection, allergy or hypersensitivity reactions independent of altered immune function?	2	Mechanisms
	7.23	Are there countermeasures for infections developed in space travel, especially latent-virus infections?	1	Countermeasures
	7.29	Are there surrogate marker assays that can be adapted to space travel that will quantitate the degree of immunodeficiency for antibody, T-cell, phagocyte, and complement function?	1	Medical Diagnosis and Treatment

* NR: Currently not rated by discipline area team

1 Risk – Title of risk and assigned risk identification number

2 CQ No.: Assigned unique critical question identification number to track each question; first digit represents the discipline area (1-12); next two digits represent sequential numbers for the questions addressing the risk

3 Critical Question: The statement of the critical question

4 Priority: The priority score of the question based on expert opinion, of the relative importance of the question for addressing/mitigating the risk; a score of "1" represents highest priority, "4" lower priority

5 Critical Question Category: The assigned category of the question in terms of the type of research or technology effort it represents (i.e., risk assessment/acceptability, underlying mechanisms/processes, countermeasures/ mitigation, medical diagnosis and treatment)

7.8 Muscle Alterations and Atrophy

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Loss of Skeletal Muscle Mass, Strength, and/or Endurance (Risk No. 28)	8.03	What is the role of, and what is necessary in order to establish the hormonal profile of astronauts during long duration spaceflight?	1	Mechanisms
	8.09	How do muscle cells sense the mechanical stress of gravity?	1	Mechanisms
	8.01	What are the appropriate prescription modalities and the compliance factors needed to minimize losses in muscle mass, strength and endurance, and facilitate rehabilitation?	1	Countermeasures
	8.02	To what extent should hormonal/pharmacological supplements be used as a countermeasure if exercise regimens are ineffective in maintaining homeostasis?	1	Countermeasures
	8.08	What are the appropriate exercise modalities and prescriptions needed to optimize skeletal muscle performance?	1	Medical Diagnosis & Treatment
Inability to Adequately Perform Tasks Due to Motor Performance, Muscle Endurance, and Disruptions in Structural and Functional Properties of Soft and Hard Connective Tissues of the Axial Skeleton (Risk No. 29)	8.03	What is the role of, and what is necessary in order to establish the hormonal profile of astronauts during long duration spaceflight?	1	Mechanisms
	8.01	What are the appropriate prescription modalities and the compliance factors needed to minimize losses in muscle mass, strength and endurance, and facilitate rehabilitation?	1	Countermeasures
	8.02	To what extent should hormonal/pharmacological supplements be used as a countermeasure if exercise regimens are ineffective in maintaining homeostasis?	1	Countermeasures
	8.08	What are the appropriate exercise modalities and prescriptions needed to optimize skeletal muscle performance?	1	Medical Diagnosis & Treatment

7.8 Muscle Alterations and Atrophy

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Inability to Sustain Muscle Performance Levels to Meet Demands of Performing Activities of Varying Intensities (Risk No. 30)	8.04	What effect does long term spaceflight/operational countermeasure has on nitrogen balance (i.e., anabolic/catabolic control of protein expression)?	1	Mechanisms/ Countermeasures
	8.05	What are the effects of long term spaceflight on the metabolism of carbohydrates and fats, and what is their influence on sustained aerobic work and performance?	1	Mechanisms
Propensity to Develop Muscle Injury, Connective Tissue Dysfunction, and Bone Fractures Due to Deficiencies in Motor Skill, Muscle Strength and Muscular Fatigue (Risk No. 31)	8.06	Do the deficits in skeletal muscle associated with long duration spaceflight affect the structural/functional properties of the sensory system and motor nerves? Describe the changes in muscle tendon interface.	1	Mechanisms
	8.07	Do structural & functional deficits in skeletal muscle system associated with long duration spaceflight impact: neurovestibular homeostasis; cardiovascular deconditioning; deficits in bone (regional & general); the muscle and tendon interface, and feedback from skeletal muscle to CNS (hypothalamus, hypophysis)?	1	Mechanisms
Impact of Deficits in Skeletal Muscle Structure and Function on Other Systems (Risk No. 32)	8.06	Do the deficits in skeletal muscle associated with long duration spaceflight affect the structural/functional properties of the sensory system and motor nerves? Describe the changes in the muscle tendon interface.	1	Mechanisms
	8.07	Do structural & functional deficits in skeletal muscle system associated with long duration spaceflight impact: neurovestibular homeostasis; cardiovascular deconditioning; deficits in bone (regional & general); the muscle and tendon interface, and feedback from skeletal muscle to CNS (hypothalamus, hypophysis)?	1	Mechanisms

1 Risk – Title of risk and assigned risk identification number

2 CQ No.: Assigned unique critical question identification number to track each question; first digit represents the discipline area (1-12); next two digits represent sequential numbers for the questions addressing the risk

3 Critical Question: The statement of the critical question

4 Priority: The priority score of the question based on expert opinion, of the relative importance of the question for addressing/mitigating the risk; a score of "1" represents highest priority, "4" lower priority

5 Critical Question Category: The assigned category of the question in terms of the type of research or technology effort it represents (i.e., risk assessment/acceptability, underlying mechanisms/processes, countermeasures/ mitigation, medical diagnosis and treatment)

*NR: Currently not rated by the discipline area team

7.9 Neurovestibular Adaptation

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Disorientation and Inability to Perform Landing, Egress, or Other Physical Tasks, Especially During/After G-Level Changes (Acute spontaneous & provoked vertigo, nystagmus, oscillopsia, poor dynamic visual acuity) **(Risk No. 33)**	9.02	What are the appropriate ground-based spaceflight analog environments that can be used as test beds for evaluating neurological adaptation time constants, adverse operational implications, countermeasures, and impacts of adaptation on other anatomical and physiological systems?	2	Risk Assessment/ Mechanisms/ Countermeasures
	9.03	How do altered time constants associated with neurological (sensorimotor, autonomic, emetic) adaptation to spaceflight (microgravity and 1/3 Mars surface) correlate with physiological and operational performance changes?	3	Risk Assessment
	9.05	How do the large inter-individual differences in response to altered magnitude and duration of gravito-inertial forces (weightlessness and return to Earth) correlate with physiological and operational performance changes?	3	Risk Assessment/ Mechanisms
	9.09	What is the physiological basis of inversion illusions, visual reorientation, and 3D memory problems in 0-G?	2	Mechanisms
	9.25	What is the physiological basis for oscillopsia, disorientation, and reduced dynamic visual acuity reported by crewmembers making head movements during re-entry?	2	Mechanisms
	9.01	What are the pros and cons of artificial gravity (AG) as a countermeasure? What are the advantages and disadvantages of large radius continuous AG vs. short radius, intermittent AG?	*1*	Countermeasures
	9.04	How do countermeasures (e.g., artificial gravity, inflight exercise, or preflight training) affect adaptation time constants?	*3*	Countermeasures
	9.08	How do visual, vestibular and haptic cues contribute to inversion illusions, visual reorientation, illusions, EVA acrophobia, disorientation and poor 3D spatial memory problems in 0-G?	*2*	Countermeasures
	9.10	Can preflight training techniques (e.g., virtual reality simulations) be used to alleviate these problems, and to evaluate emergency procedures?	*2*	Countermeasures
	9.27	How can 0-G immersive teleoperation displays be designed to reduce disorientation and/or motion sickness?	*2*	Countermeasures

7.9 Neurovestibular Adaptation (Continued)

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Impaired Neuromuscular Coordination and/or Strength (Gait ataxia, postural instability) **(Risk No. 34)**	9.02	What are the appropriate ground-based spaceflight analog environments that can be used as test beds for evaluating neurological adaptation time constants, adverse operational implications, countermeasures, and impacts of adaptation on other anatomical and physiological systems?	2	Risk Assessment/ Mechanisms/ Countermeasures
	9.05	How do the large inter-individual differences in response to altered magnitude and duration of gravito-inertial forces (weightlessness and return to Earth) correlate with physiological and operational performance changes?	3	Risk Assessment/ Mechanisms
	9.22	What is the relative contribution of neurovestibular adaptation, neuromuscular deconditioning, and orthostatic intolerance to postflight neuromuscular coordination, ataxia and locomotion difficulties?	2	Risk Assessment/ Mechanisms
	9.01	What are the pros and cons of artificial gravity (AG) as a countermeasure? What are the advantages and disadvantages of large radius continuous AG vs. short radius, intermittent AG?	1	Countermeasures
	9.04	How do countermeasures (e.g., artificial gravity, inflight exercise, or preflight training) affect adaptation time constants?	3	Countermeasures
	9.24	Can preflight or inflight training, or sensory aids and prostheses, improve postlanding postural and locomotor control?	2	Countermeasures

7.9 Neurovestibular Adaptation

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Impaired Cognitive and/or Physical Performance Due to Motion Sickness Symptoms or Treatments, Especially During/After G-level Changes (Including short term memory loss, reaction time increase, drowsiness, fatigue, torpor, irritability, ketosis) **(Risk No. 35)**	9.11	What physical and cognitive performance will be required of the crew during the acceleration/deceleration portions of the mission?	2	Risk Assessment
	9.26	What is the physiological basis of space motion sickness? How does chronic space motion sickness (including sopite syndrome) affect mood, initiative, and interpersonal relationships?	2	Mechanisms
	9.12	How effective is promethazine injection (or other drugs) in providing fast relief in mission critical situations? Does the drug have unacceptable side effects, particularly the short term effects on cognitive function?	1	Countermeasures
	9.23	To what extent can neurovestibular adaptation to weightlessness and/or artificial gravity take place in context specific fashion, so crewmembers can be adapted to multiple environments and switch between them without suffering disorientation or motion sickness?	2	Countermeasures
	9.27	How can 0-G immersive teleoperation displays be designed to reduce disorientation and/or motion sickness?	2	Countermeasures

7.9 Neurovestibular Adaptation (Continued)

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Vestibular Contribution to Cardioregulatory Dysfunction (Postlanding orthostatic intolerance, sleep and mood changes) **(Risk No. 36)**	9.22	What is the relative contribution of neurovestibular adaptation, neuromuscular deconditioning, and orthostatic intolerance to postflight neuromuscular coordination, ataxia and locomotion difficulties?	2	Risk Assessment / Mechanisms / Countermeasures
	9.15	Does neurovestibular adaptation to weightlessness impair postlanding cardiovascular regulation and contribute to orthostatic intolerance?	1	Mechanisms
	9.17	How does neurovestibular adaptation contribute to postlanding postural control and locomotion difficulties?	2	Mechanisms
	9.16	Do vestibular countermeasures improve postlanding cardiovascular regulation and orthostatic tolerance?	1	Countermeasures
	9.23	To what extent can neurovestibular adaptation to weightlessness and/or artificial gravity take place in context specific fashion, so crewmembers can be adapted to multiple environments and switch between them without suffering disorientation or motion sickness?	2	Countermeasures
Possible Chronic Impairment of Orientation or Balance Function Due to Microgravity or Radiation (Imbalance, gait ataxia, vertigo, chronic vestibular insufficiency, poor dynamic visual acuity) **(Risk No. 37)**	9.20	What are the significant irreversible changes in sensory-motor neurological function associated physiological systems, and anatomical and/or biochemical processes that may be caused by exposure or development in long duration 0-G or partial-G, and what are the mechanisms and time course?	4	Mechanisms
	9.21	How can these changes be optimally distinguished from the normal responses to stress, isolation, and normal background physiological variability? What countermeasures can be developed?	4	Countermeasures
	9.24	Can preflight or inflight training, or sensory aids and protheses, improve postlanding postural and locomotor control?	2	Countermeasures

1 Risk – Title of risk and assigned risk identification number

2 CQ No.: Assigned unique critical question identification number to track each question; first digit represents the discipline area (1-12); next two digits represent sequential numbers for the questions addressing the risk

3 Critical Question: The statement of the critical question

4 Priority: The priority score of the question based on expert opinion, of the relative importance of the question for addressing/mitigating the risk; a score of "1" represents highest priority, "4" lower priority

5 Critical Question Category: The assigned category of the question in terms of the type of research or technology effort it represents (i.e., risk assessment/acceptability, underlying mechanisms/processes, countermeasures/ mitigation, medical diagnosis and treatment)

*NR: Currently not rated by the discipline area team

7.10 Radiation Effects

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Carcinogenesis Caused by Radiation (Risk No. 38)	10.09	What are the cancer risks in humans from spaceflight?	1	Risk Assessment
	10.11	What is the acceptable accuracy for risks of acute and late effects in humans from photons to adequately extrapolate to space?	1	Risk Assessment
	10.05	Are there unique biological effects associated with HZE's?	1	Mechanisms
	10.07	How can animal and cell experiments be done and data best be used to extrapolate to the human risk from space radiation?	1	Mechanisms
	10.10	What are the risks from SPE's and what is their impact on operations, EVAs and surface exploration?	1	Risk Assessment
	10.08	How do the thickness, design, and material composition of space vehicles affect the internal radiation environment and biological assessment?	1	Countermeasures
	10.06	Do we have strategies for calculating risks that are adequate if expected data are provided and what are uncertainties?	2	Countermeasures
	10.04	Are there differences in response to particles with similar LET, but with different atomic numbers and energies?	2	Mechanisms
	10.12	What are the effects of age, gender, and inter-individual diversity?	2	Mechanisms
	10.01	Are the biological effects for protons above 10 MeV sufficiently similar to photons that photon data can be used for their consequences?	3	Mechanisms
	10.03	Are there chemopreventive or biological agents which would mitigate acute or late effects?	3	Countermeasures

7.10 Radiation Effects (Continued)

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Late Degenerative Tissue Damage including Non-cancer mortality, Cataracts, and Central Nervous System Effects (Risk No. 39)	10.05	Are there unique biological effects associated with HZE's?	1	Risk Assessment
	10.07	How can animal and cell experiments be done and data best be used to extrapolate to the human risk from space radiation?	1	Risk Assessment
	10.10	What are the risks from SPE's and what is their impact on operations, EVAs and surface exploration?	1	Risk Assessment
	10.08	How do the thickness, design, and material composition of space vehicles affect the internal radiation environment and biological assessment?	1	Countermeasures
	10.11	What is the acceptable accuracy for risks of acute and late effects in humans from photons to adequately extrapolate to space?	2	Risk Assessment
	10.04	Are there differences in response to particles with similar LET, but with different atomic numbers and energies?	2	Mechanisms
	10.12	What are the effects of age, gender, and inter-individual diversity?	2	Mechanisms
	10.06	Do we have strategies for calculating risks that are adequate if expected data are provided and what are uncertainties?	3	Risk Assessment
	10.01	Are the biological effects for protons above 10 MeV sufficiently similar to photons that photon data can be used for their consequences?	3	Mechanisms
	10.03	Are there chemopreventive or biological agents which would mitigate acute or late effects?	3	Countermeasures
Synergistic Effects from Exposure to Radiation, Microgravity, and Other Spacecraft Environmental Factors (Risk No. 40)	10.09	What are the cancer risks in humans from spaceflight?	1	Risk Assessment
	10.02	Are there adverse synergisms between radiation and other space environmental and biological factors?	1	Mechanisms
	10.07	How can animal and cell experiments be done and data best be used to extrapolate to the human risk from space radiation?	1	Risk Assessment
	10.05	Are there unique biological effects associated with HZE's?	2	Mechanisms
	10.06	Do we have strategies for calculating risks that are adequate if expected data are provided and what are uncertainties?	2	Countermeasures
	10.12	What are the effects of age, gender, and inter-individual diversity?	2	Mechanisms
	10.03	Are there chemopreventive or biological agents which would mitigate acute or late effects?	3	Countermeasures

7.10 Radiation Effects

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Early or Acute Effects from Radiation Exposure (Risk No. 41)	10.11	What is the acceptable accuracy for risks of acute and late effects in humans from photons to adequately extrapolate to space?	1	Risk Assessment
	10.07	How can animal and cell experiments be done and data best be used to extrapolate to the human risk from space radiation?	1	Risk Assessment
	10.10	What are the risks from SPE's and what is their impact on operations, EVAs and surface exploration?	1	Risk Assessment
	10.08	How do the thickness, design, and material composition of space vehicles affect the internal radiation environment and biological assessment?	1	Countermeasures
	10.05	Are there unique biological effects associated with HZE's?	2	Mechanisms
	10.06	Do we have strategies for calculating risks that are adequate if expected data are provided and what are uncertainties?	2	Risk Assessment
	10.12	What are the effects of age, gender, and inter-individual diversity?	2	Mechanisms
	10.04	Are there differences in response to particles with similar LET, but with different atomic numbers and energies?	2	Risk Assessment
	10.01	Are the biological effects for protons above 10 MeV sufficiently similar to photons that photon data can be used for their consequences?	3	Mechanisms
	10.03	Are there chemopreventive or biological agents which would mitigate acute or late effects?	3	Countermeasures
Radiation Effects on Fertility, Sterility and Heredity (Risk No. 42)	10.12	What are the effects of age, gender, and inter-individual diversity?	3	Mechanisms
	10.13	What are the risks associated with fertility, sterility, and hereditary effects as a result of exposure to radiation on long duration missions?	3	Mechanisms

1 Risk – Title of risk and assigned risk identification number

2 CQ No.: Assigned unique critical question identification number to track each question; first digit represents the discipline area (1-12); next two digits represent sequential numbers for the questions addressing the risk

3 Critical Question: The statement of the critical question

4 Priority: The priority score of the question based on expert opinion, of the relative importance of the question for addressing/mitigating the risk; a score of "1" represents highest priority, "4" lower priority

5 Critical Question Category: The assigned category of the question in terms of the type of research or technology effort it represents (i.e., risk assessment/acceptability, underlying mechanisms/processes, countermeasures/ mitigation, medical diagnosis and treatment)

*NR: Currently not rated by the discipline area team

7.11 Clinical Capabilities

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Trauma and Acute Medical Problems (Risk No. 43)	11.01	What are the essential technologies, resources, procedures, skills and training necessary to provide effective advanced life support (CPR, ACLS, ATLS) in space?	1	Medical Diagnosis and Treatment
	11.02	What acute and chronic diagnostic and monitoring capabilities (hardware, software, communication and data management capabilities, "smart" systems, and training) is necessary to support acute trauma, surgical and medical intervention in space?	1	Medical Diagnosis and Treatment
	11.03	What medical imaging and telemedicine (including medical informatics) capabilities (technology, skills and training) are necessary to support space medicine?	1	Medical Diagnosis and Treatment
	11.04	What are the specific techniques, resources, protocols, skills and equipment (technology) necessary to perform surgical intervention and care in the space environment (including options and techniques for anesthesia)?	2	Medical Diagnosis and Treatment
	11.05	What are effective methods and technologies for fluid (IV and other) resuscitation and transfusion in space (including blood replacement products)?	2	Medical Diagnosis and Treatment
	11.06	What are the optimal treatment methods, technologies, and protocols for the on-orbit management of acute musculoskeletal injuries (including sprains, strains, contusions and fractures)?	2	Countermeasures / Medical Diagnosis and Treatment
	11.07	What are the most effective options, protocols, and technologies to support patient transport and return to Earth definitive medical care facility?	2	Medical Diagnosis and Treatment
	11.08	What are the optimal technologies for supporting an autonomous acute medical response capability in space, including medical informatics, smart medical care systems, on orbit skills maintenance and training?	1	Medical Diagnosis and Treatment
	11.09	What are the procedures and protocols for pronouncement of death in space and for the management of a cadaver?	3	Medical Diagnosis and Treatment
	11.10	What are the essential technologies, resources, skills, and training necessary to effectively diagnose, treat, and recover patients from likely acute medical emergencies in space including, but not limited to: wounds, lacerations, and burns; toxic exposure and acute anaphylaxis; acute radiation illness; dental emergencies; ophthalmologic emergencies; gynecologic and urology emergencies; psychiatric emergencies	1	Medical Diagnosis and Treatment
	11.11	What are the technologies, methods, resources, and skills necessary to accomplish chronic care and recovery following an acute medical or surgical event in space?	1	Medical Diagnosis and Treatment
	11.12	What technologies are feasible and should be developed to support non-invasive or minimally invasive medical diagnosis and intervention capabilities in space?	1	Medical Diagnosis and Treatment

7.11 Clinical Capabilities

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Toxic Exposure (Risk No. 44)	11.13	What diagnostic, monitoring and treatment capabilities are essential for management of toxic exposure (acute and chronic)?	1	Medical Diagnosis and Treatment
	11.14	What crew screening and selection criteria should be developed and implemented to identify individuals who are at increased risk for developing hypersensitivity or allergies to spaceflight compounds, exposures, or payloads?	2	Risk Assessment and Countermeasures
	11.15	What countermeasures should be developed and implemented to prevent adverse reactions to toxic exposures (e.g. sleep, nutritional, medications, stress reduction, shielding, protective equipment, etc.)?	2	Countermeasures
Altered Pharmacodynamics and Adverse Drug Reactions (Risk No. 45)	11.16	What are the effects and implications of spaceflight alterations in human physiology on the absorption, distribution, metabolism, clearance, excretion, clinical efficacy, side effects and drug interactions for clinically useful medications?	2	Mechanisms
	11.17	What technologies are available to provide extended shelf-life pharmaceuticals for long duration spaceflight?	1	Countermeasures
	11.18	What are the side effect and interaction profiles of the commonly use medications in spaceflight, and how should the crew and medical team be trained and prepared to recognize and deal with these issues?	2	Mechanisms / Medical Diagnosis and Treatment
	11.19	What are the most appropriate dosages and routes of administration for the spaceflight clinically useful medications (taking into consideration the answers to CQ 11.16)?	1	Mechanisms / Medical Diagnosis and Treatment
	11.20	What diagnostic and laboratory technologies are necessary to predict and manage medication side effects, interactions, and toxicity during spaceflight?	1	Risk Assessment and Acceptability / Medical Diagnosis and Treatment
	11.21	What is the effectiveness, indications and risks, and proper utilization of popular non-traditional herbal and nutritional supplements and other alternative therapies (such as homeopathy, etc.)?	3	Mechanisms

7.11 Clinical Capabilities (Continued)

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Illness and Ambulatory Health Problems (Risk No. 46)	11.22	What are the methods, technologies, and standards for conducting a nominal health and fitness examination in space (including interval history and physical, baseline diagnostics, and data management)?	1	Medical Diagnosis and Treatment
	11.23	What are the clinical norms for metabolic and physiologic variables in the space-adapted individual (including clinical laboratory and imaging norms)?	1	Medical Diagnosis and Treatment
	11.24	What are the signs, symptoms or abnormal examination findings (Including laboratory) associated with diseases observed in space?	1	Medical Diagnosis and Treatment
	11.25	What is the risk and incidence of illness and injury associated with spaceflight?	1	Risk Assessment
	11.26	What are the essential technologies, methods, resources, skills and training necessary to support physical examination, diagnosis, monitoring and treatment of illnesses and ambulatory health problems in space (including telemedicine, medical informatics, and smart medical systems)?	2	Medical Diagnosis and Treatment
	11.27	What are the technologies, procedures, and resources necessary for management of medical waste products during space?	2	Countermeasures
	11.28	What are the impacts from and issues related to communication delay on spaceflight health care and telemedicine, and what are the technologies, protocols, and skills necessary for an autonomous health care capability in space as a result of communication delay?	1	Countermeasures
	11.29	What are the provisions, technologies, methods and skills necessary to support environmental health-related diagnosis and monitoring including microbiological, toxicological, noise and radiation issues?	1	Medical Diagnosis and Treatment
	11.30	What are the optimal protocols, technologies, resources, skills and training necessary to diagnose, monitor, treat and recover patients in space from the expected illnesses and ambulatory medical problems, including but not limited to: orthopedic and musculoskeletal problems; infectious, hematological and immune-related diseases; dermatological, ophthalmologic, and ENT problems; nutritional, metabolic, and endocrine disorders; dental problems; gastrointestinal and urologic disorders; and behavioral, fatigue and stress-related problems?	1	Countermeasures ' Medical Diagnosis and Treatment
	11.31	What technologies can be developed and implemented to provide computer-assisted, "smart" modeling of the human system in space that can be used for individual patient modeling, monitoring, diagnosis, and prevention (predictive modeling)?	1	Countermeasures / Medical Diagnosis and Treatment
	11.32	What are alternative approaches to traditional medicine that have potential merit and should be investigated as potential adjunctive therapy for space medicine (such as biofeedback, massage therapy, musculoskeletal manipulation, acupuncture, magnet therapy)?	3	Countermeasures

7.11 Clinical Capabilities (Continued)

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Prevention Decompression Sickness in NASA Operations (Risk No. 47)	11.33	What are the strategies to mitigate the risk of decompression sickness during all NASA operations (i.e., extravehicular activities from the International Space Station and future habitats beyond LEO, during training activities in underwater facilities, or altitude chambers, during flight using NASA aircraft, and in research designed to prevent decompression sickness)?	1	Countermeasures / Medical Diagnosis and Treatment
	11.35	What are the best models (physiological, statistical, biophysical) to mitigate the risk of decompression sickness in all NASA operations?	2	Medical Diagnosis and Treatment
	11.34	Given that is possible to mitigate the risk of DCS through exercise, what are the most effective prescriptions involving exercise (type and intensity) and prebreathe duration for different mission scenarios?	1	Countermeasures / Medical Diagnosis and Treatment
	11.40	How can information provided by an in-suit Doppler bubble detector be used to mitigate the risk of decompression sickness in all NASA operations involving decompression?	1	Risk Assessment
	11.41	What are the mechanisms of nitrogen washout in microgravity with and without exercise during oxygen pre-breathing?	3	Mechanisms
	11.42	What are the best procedures to accurately quantify and characterize breaks during prebreathe protocols during NASA operations involving decompression, especially during breaks in exercise?	1	Countermeasures

7.11 Clinical Capabilities (Continued)

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]

	11.43	What is the role of micronuclei formation, stability, and resolution in blood and tissues on reduction of decompression sickness risk during all NASA operations involving decompression?	3	Mechanisms
	11.44	Under what conditions does the presence of Patent Foramen Ovale (PFO) increase the risk of Type II (serious) decompression sickness in NASA operations involving decompression?	1	Risk Assessment
	11.45	Is it possible and what are the DCS risk mitigation options fro interplanetary EVA (e.g., moon and Mars) given that a tri-gas breathing mixture that includes argon is present?	4	Mechanisms
	11.46	What is the role of individual susceptibility, age, and gender on the risk of DCS during NASA operations involving decompression?	3	Mechanisms
	11.47	What are the best strategies, and how do you implement them to treat decompression sickness during all NASA operations involving decompression?	1	Medical Diagnosis & Treatment
	11.48	What are the available and new technologies needed to provide hyperbaric treatment options on the ISS and future habitats (or vehicles) beyond LEO (e.g., on the moon or Mars)? What are the available or new technologies to deliver oxygen to a patient, including the use of perflurocarbon emulsions? What available new technologies are available to provide life support (e.g., thermal control, telemedicine communications) during hyperbaric treatment in microgravity or on the surface of the moon or Mars? What are the available or new technologies to monitor astronauts with serious decompression sickness?	1	Medical Diagnosis & Treatment
	11.49	What are the available and new technologies needed to aid in the diagnosis of decompression sickness on the International Space Station and future habitats beyond LEO?	1	Medical Diagnosis & Treatment
Difficulty of Rehabilitation Following Landing (Risk No. 48)	11.36	What are the expected effects and risks of long duration spaceflight related to landing, egress and post-landing performance (in various anticipated gravitational environments)?	1	Mechanisms
	11.39	What are the issues related to and resources required for long term rehabilitation and recovery from long duration spaceflight?	2	Medical Diagnosis and Treatment
	11.38	What pre-landing and pre-egress performance and health parameters should be monitored to assure adequate cardiovascular tone, neurological function, skeletal integrity, muscular strength, and endurance?	2	Medical Diagnosis and Treatment
	11.37	What are the essential technologies, resources, protocols, skills and training necessary for post-landing performance, recovery and rehabilitation (including psychological, cardiovascular, neurosensory, musculoskeletal, and nutritional)?	1	Countermeasures / Medical Diagnosis and Treatment

1 Risk – Title of risk and assigned risk identification number

2 CQ No.: Assigned unique critical question identification number to track each question; first digit represents the discipline area (1-12); next two digits represent sequential numbers for the questions addressing the risk

3 Critical Question: The statement of the critical question

4 Priority: The priority score of the question based on expert opinion, of the relative importance of the question for addressing/mitigating the risk; a score of "1" represents highest priority, "4" lower priority

[5] Critical Question Category: The assigned category of the question in terms of the type of research or technology effort it represents (i.e., risk assessment/acceptability, underlying mechanisms/processes, countermeasures/ mitigation, medical diagnosis and treatment)

*NR: Currently not rated by the discipline area team

7.12 Multisystem (Cross Risk) Alterations)

Risk[1]	CQ No.[2]	Critical Question[3]	CQ Priority[4]	Critical Question & Risk Mitigation/ CM Category[5]
Postlanding Alterations in Various Systems Resulting in Performance Decrements and Injuries (Risk No. 49)	12.01	How do alterations in cardiovascular function associated with spaceflight affect the functioning of other systems?	2	Mechanisms
	12.02	How do alterations in neural, endocrine, and metabolic function associated with spaceflight affect cardiovascular functioning and the functioning of other organ systems?	2	Mechanisms
	12.03	What rehabilitative measures should be applied after mission completion?	2	Countermeasures

1 Risk – Title of risk and assigned risk identification number

2 CQ No.: Assigned unique critical question identification number to track each question; first digit represents the discipline area (1-12); next two digits represent sequential numbers for the questions addressing the risk

3 Critical Question: The statement of the critical question

4 Priority: The priority score of the question based on expert opinion, of the relative importance of the question for addressing/mitigating the risk; a score of "1" represents highest priority, "4" lower priority

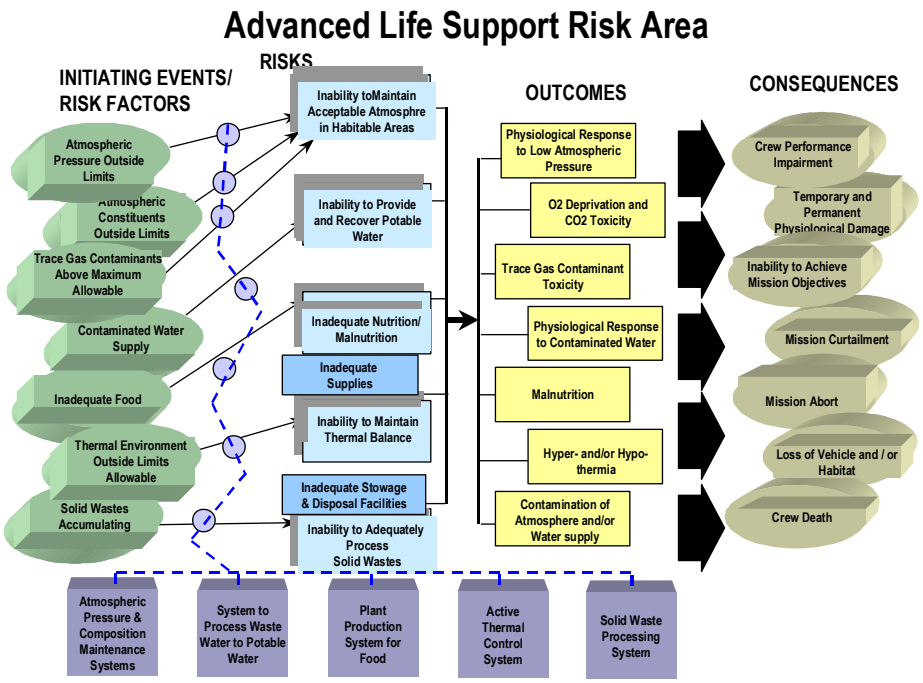
5 Critical Question Category: The assigned category of the question in terms of the type of research or technology effort it represents (i.e., risk assessment/acceptability, underlying mechanisms/processes, countermeasures/ mitigation, medical diagnosis and treatment)

*NR: Currently not rated by the discipline area team

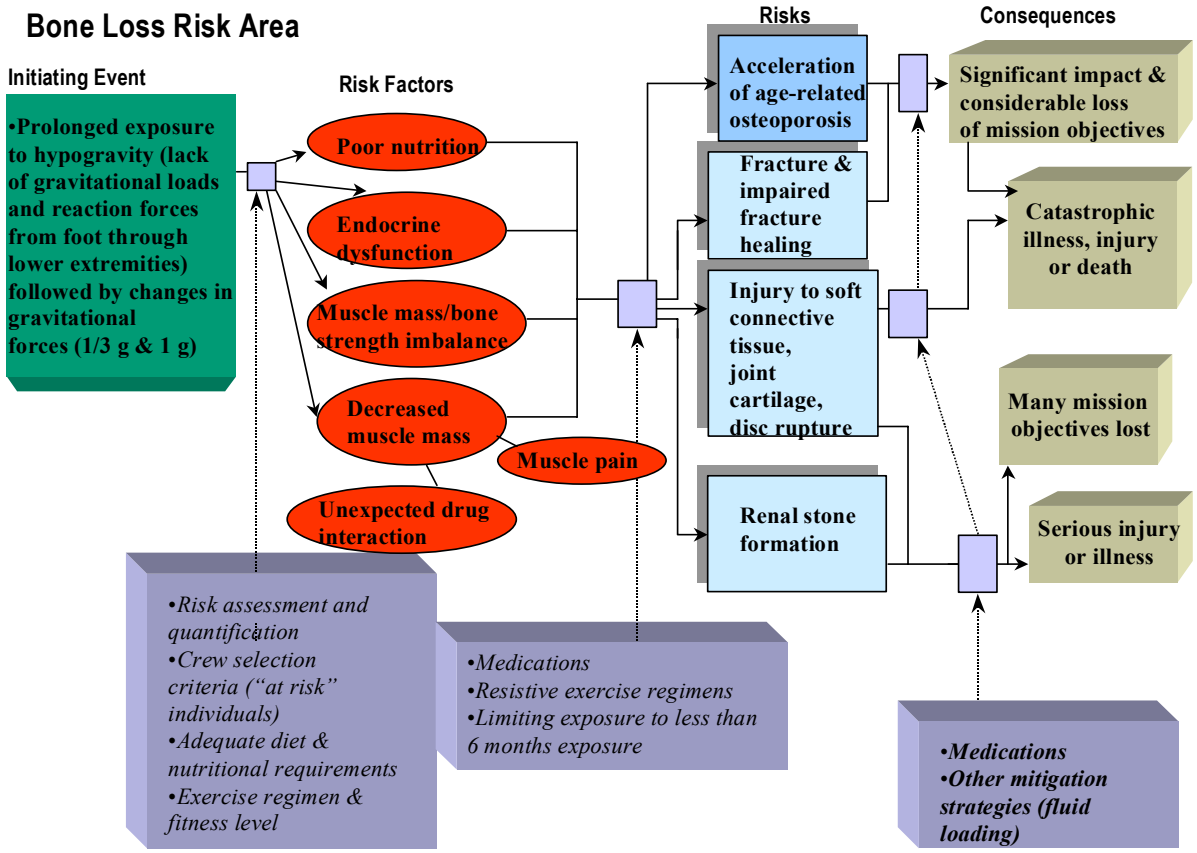
8.0 Roadmaps

Roadmaps are graphic models developed to depict a causal pathway. Each "Roadmap" shows the interrelationship among initiating events, risk factors, risks and consequences within each of the Discipline Areas. The points at where to intervene in the process to alter the occurrence or consequences of the risk are shown as well as the different types of risk mitigations/countermeasures required to reduce and/or prevent the risk. There is no time dimension associated with the maps other than the causal sequence of events and their consequences. The timelines for individual risks are currently under development.

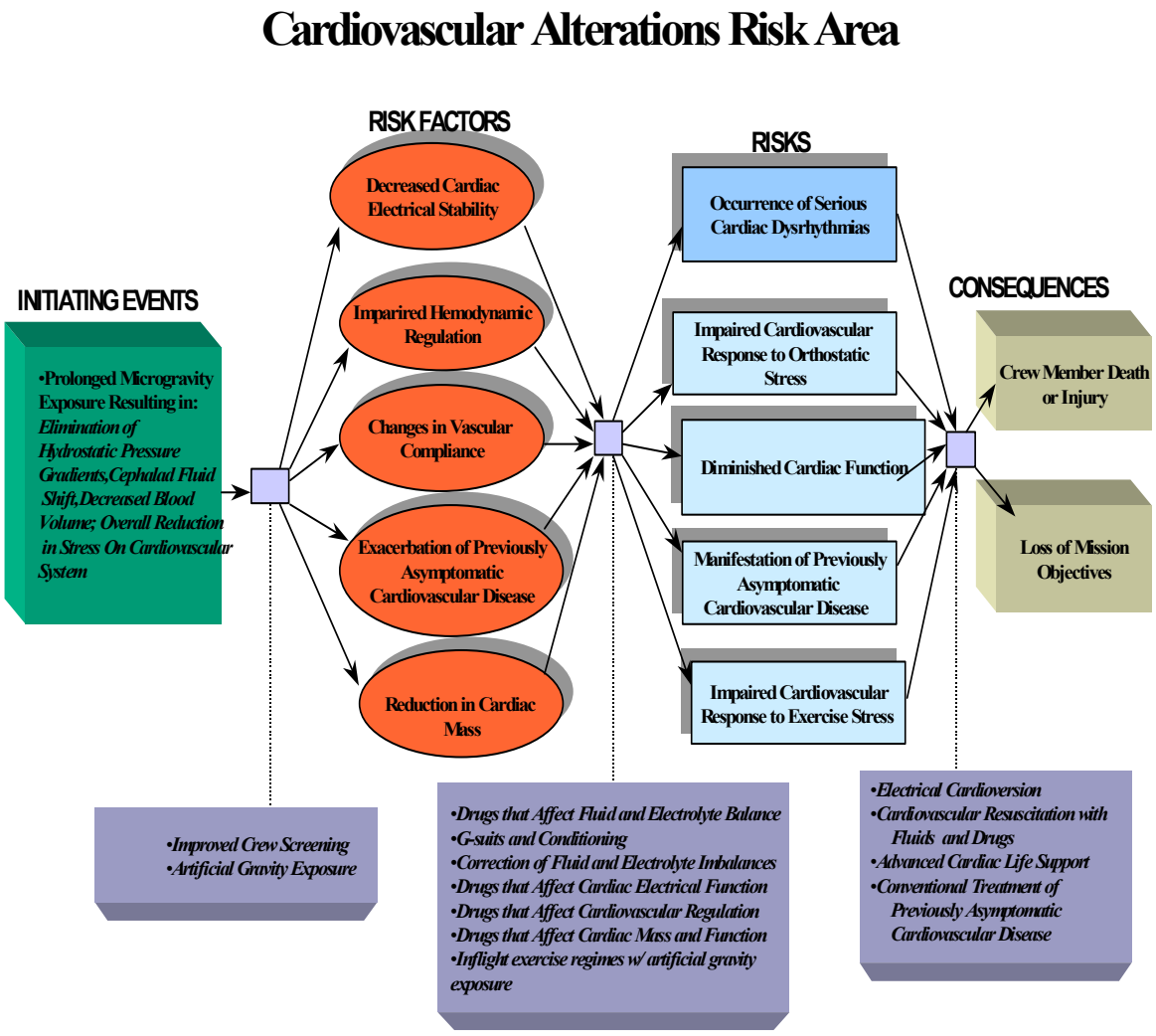
8.1 Advanced Life Support Roadmap



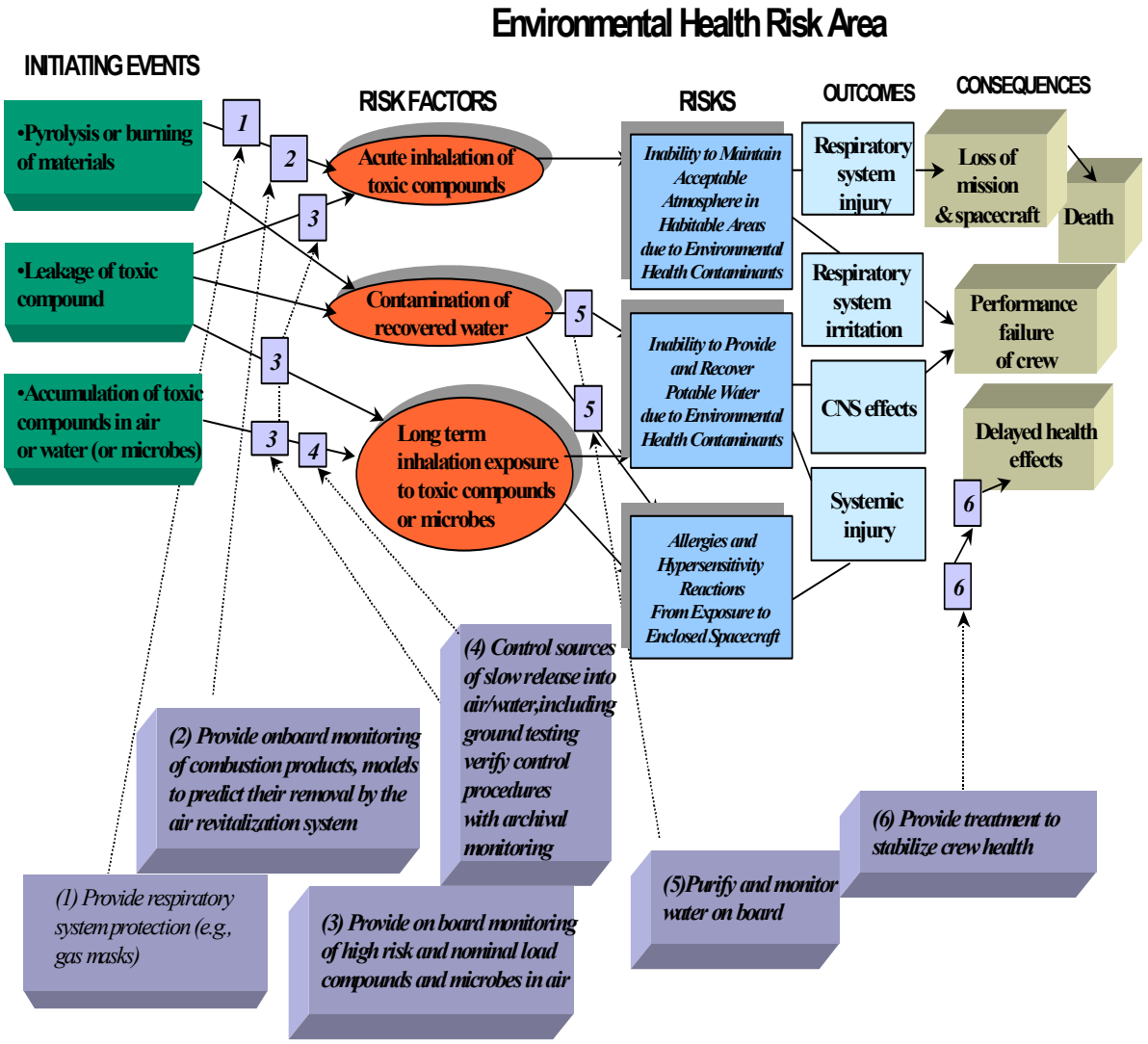
8.2 Bone Loss Roadmap



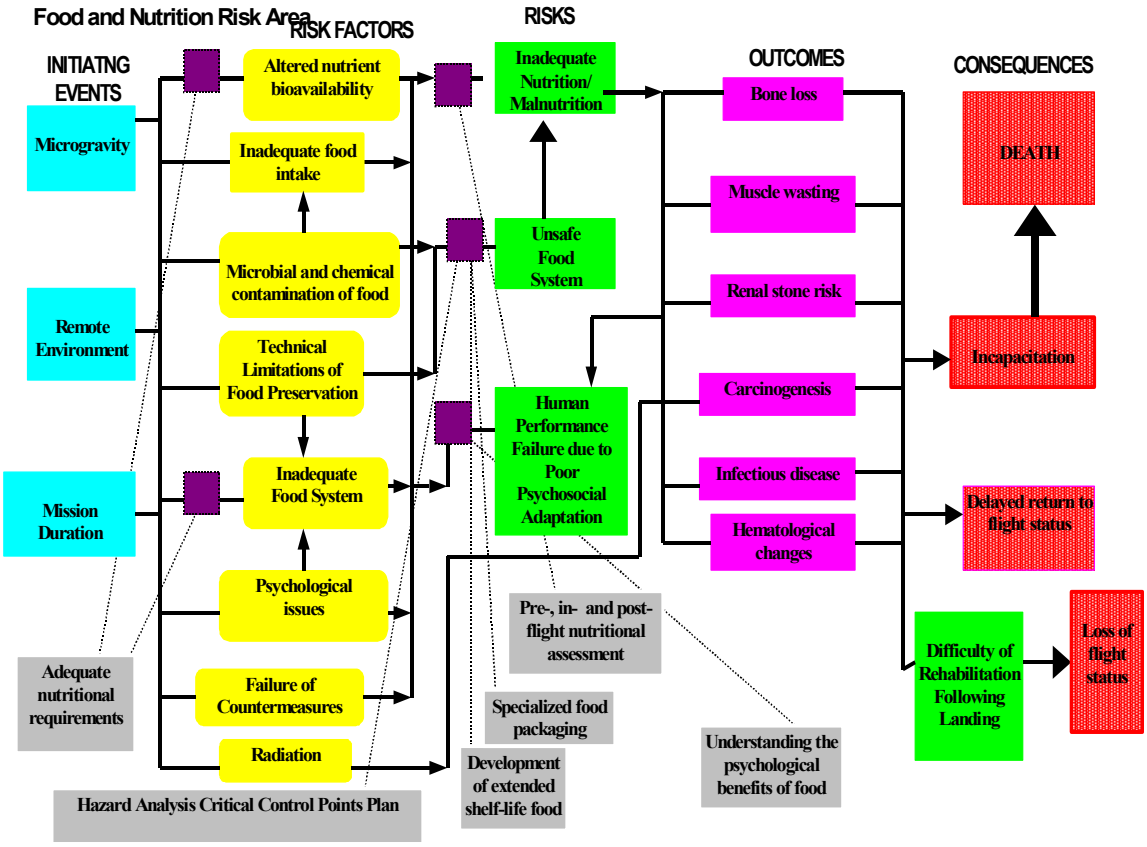
8.3 Cardiovascular Alterations Roadmap



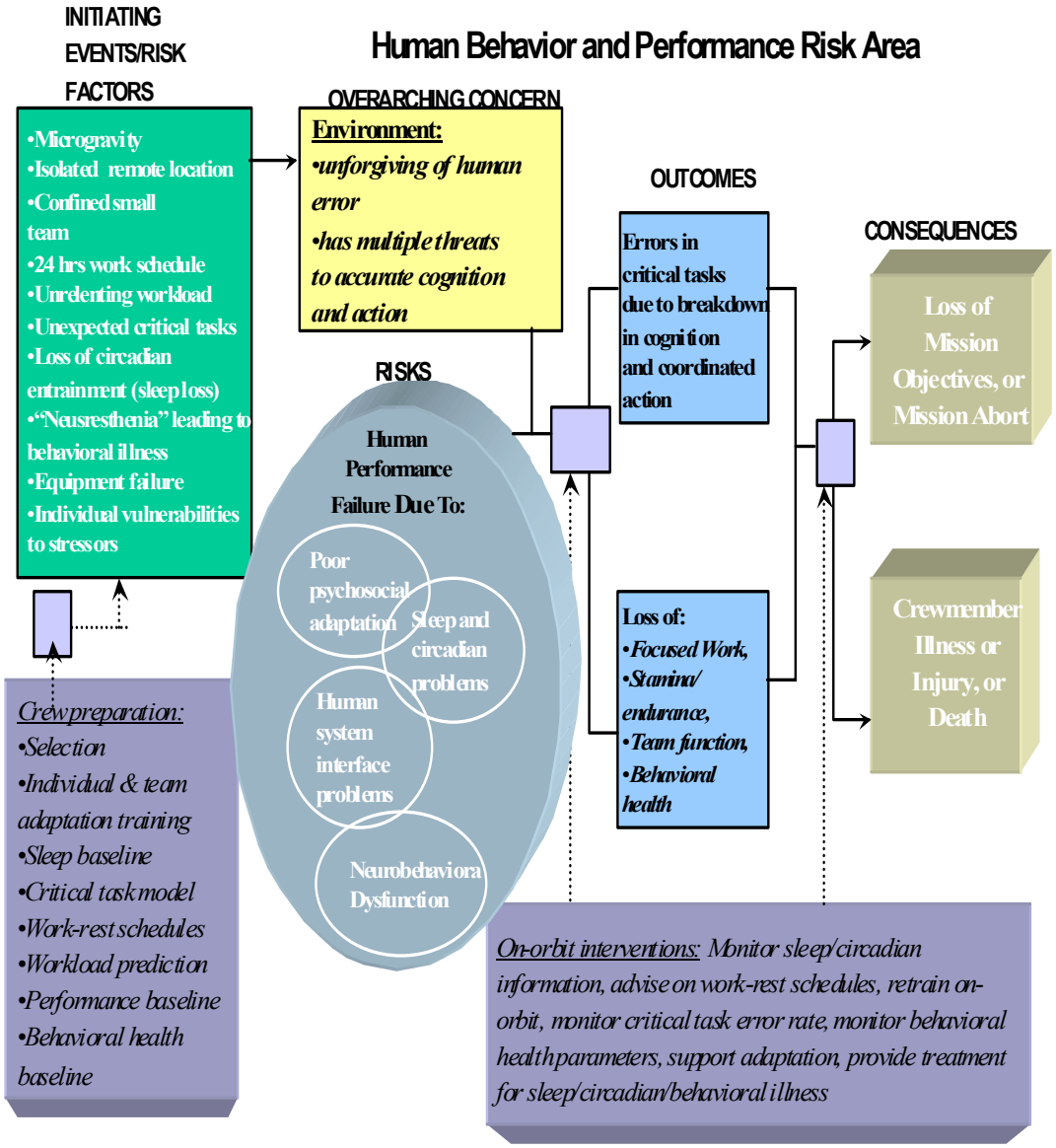
8.4 Environmental Health Roadmap



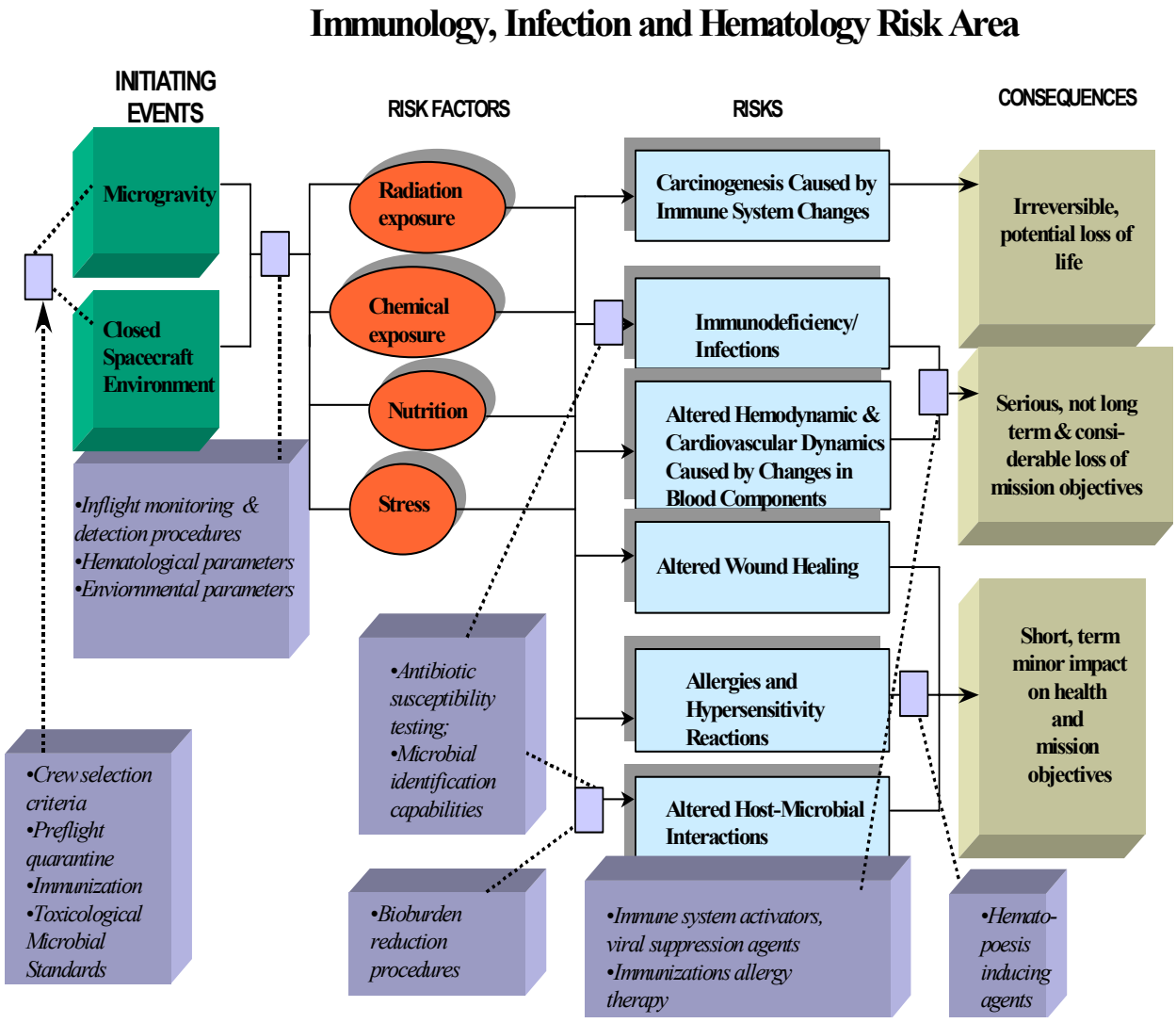
8.5 Food and Nutrition Roadmap



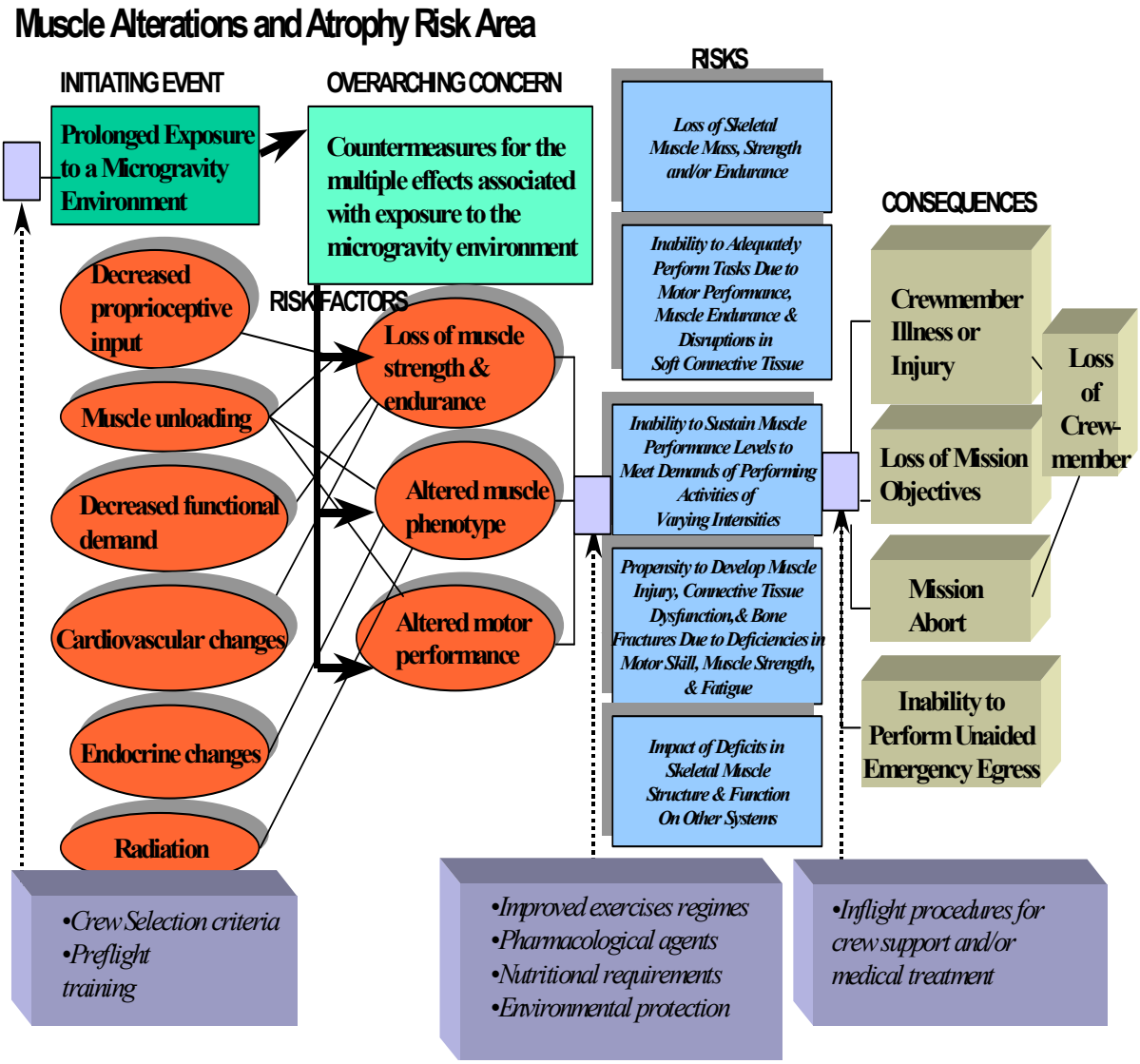
8.6 Human Behavior and Performance Roadmap



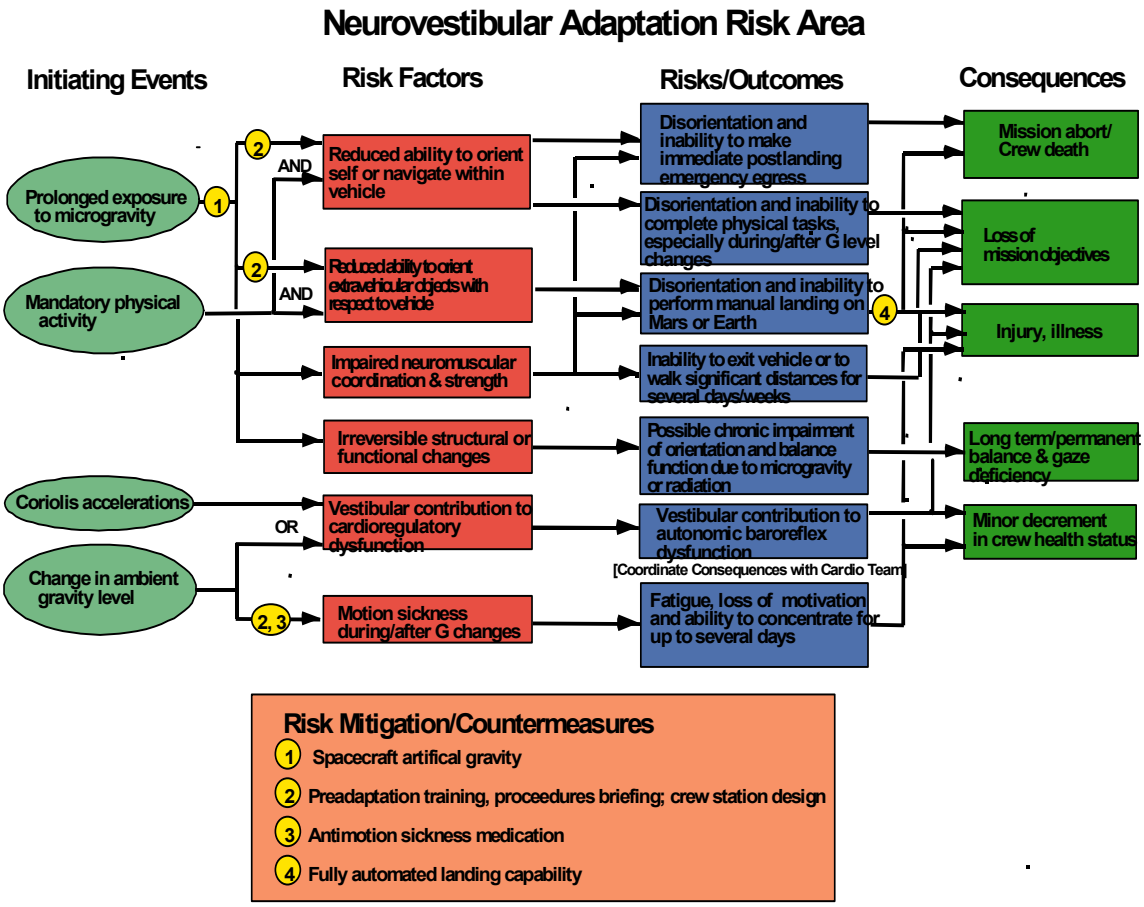
8.7 Immunology, Infection and Hematology Roadmap



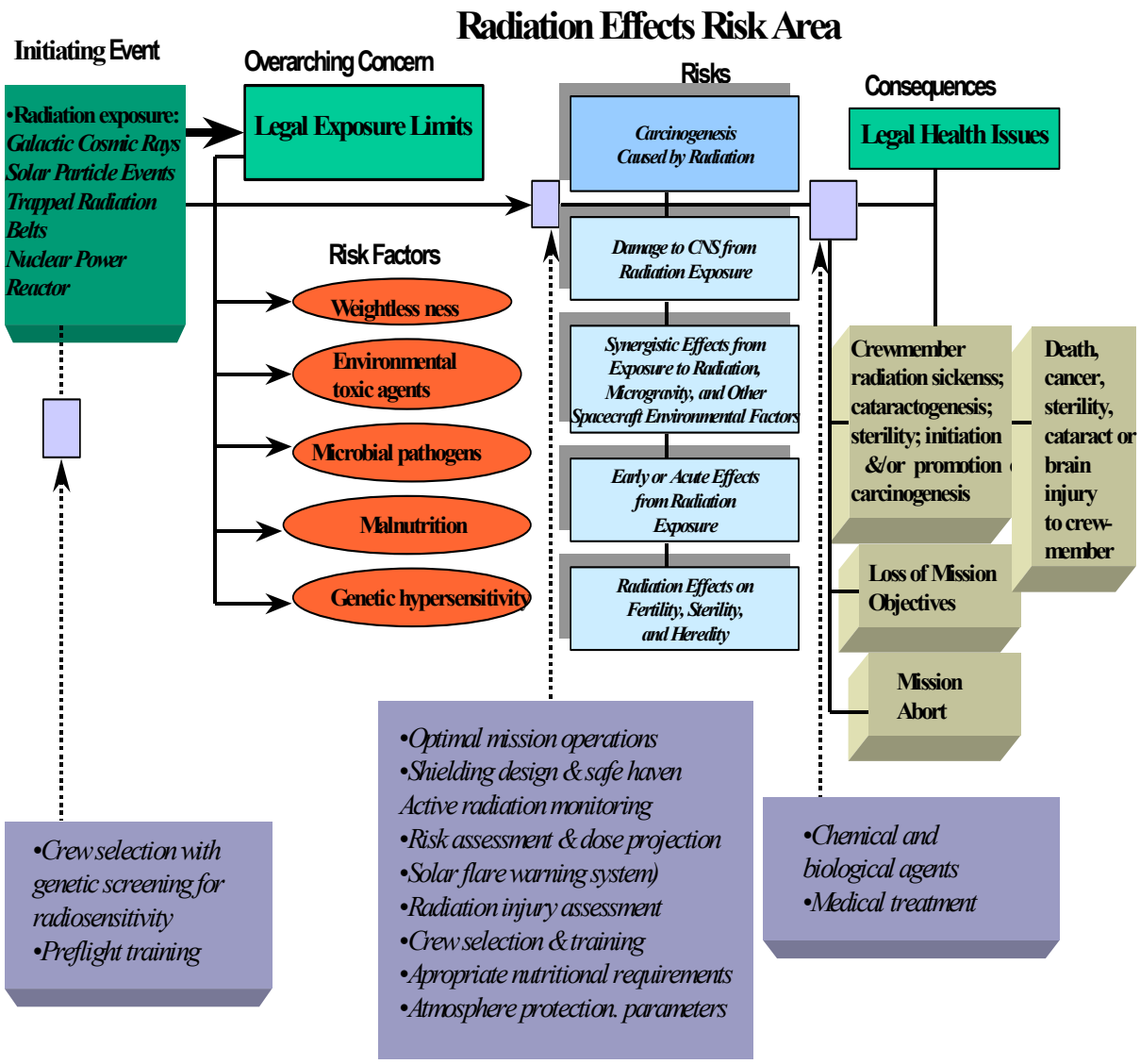
8.8 Muscle Alterations and Atrophy Roadmap



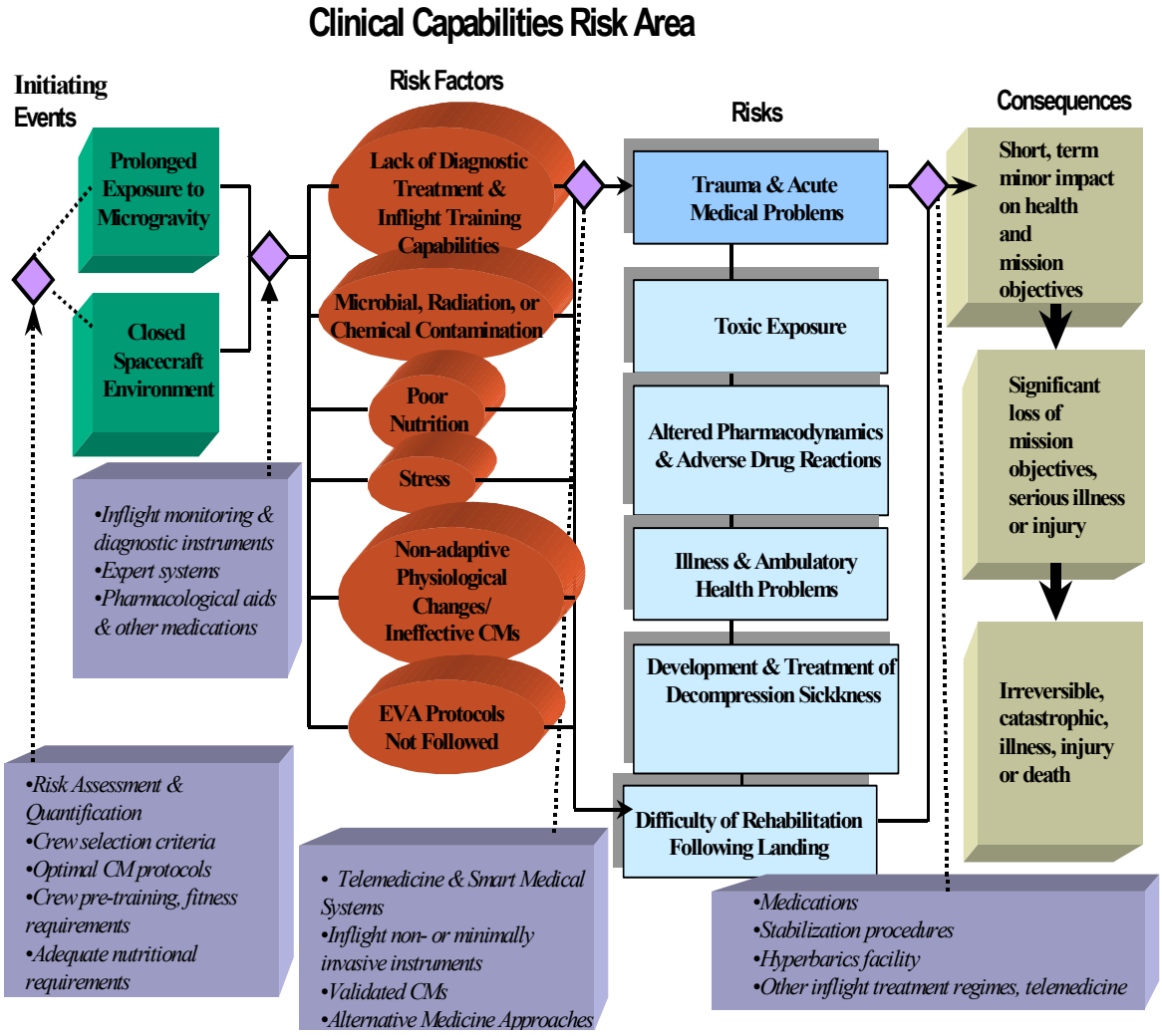
8.9 Neurovestibular Adaptation Roadmap



8.10 Radiation Effects Roadmap



8.11 Clinical Capabilities Roadmap



9.0 Appendices

A-1 – Risk Scoring Criteria

(1) Expected Occurrence of Risk
Score the expected occurrence of the risk under the two following conditions: (a) when no countermeasures or risk mitigation strategies are present; and (b) when current countermeasures or risk mitigation strategies are applied

(a) no countermeasures or risk mitigation strategies present

1= 0-5 %
2= 6-20%
3= 21-60%
4= 61-94%
5= ≥95-100%

(b) current countermeasures are applied

1= 0-5 %
2= 6-20%
3= 21-60%
4= 61-94%
5= ≥95-100%

(2) Expected Impact on Mission: If the risk were to occur what would its expected impact be on the mission in terms of mission objectives?
Score the expected mission impact of the risk on a 1 - 5 scale, where "1"=no impact or loss of mission objectives and "5"=mission abort

1 = *no impact to mission whatsoever; no loss of mission objectives*
2 = *relatively small impact to mission; loss limited to only a few of the mission objectives*
3 = *considerable impact and considerable loss of mission objectives*
4 = *significant mission impact; many mission objectives lost, however mission is not aborted*
5 = *significant mission impact; total loss of mission objectives; mission aborted*

(3) Expected Impact on Crew: If the risk were to occur what would its expected impact be on crew health and safety?
Score the expected impact to the crew according to a 1 - 5 scale, where "1"= no impact or impairment, and "5" = significant, irreversible, long-term impairment, or death.

1 = *no impact to crew*
2 = *short-term, minor injury, illness, incapacitation, or impairment to crewmember*
3 = *serious injury, illness, incapacitation or impairment but not long term*
4 = *significant and long term impairment, but not permanent*
5 = *irreversible, catastrophic impairment, or death*

(4) Risk Mitigation Status:
Score the current status of the risk mitigation strategy or countermeasure to address each risk, where "1" equals mitigation status completed and understood (risk mitigated) and "5" equals no mitigation available and substantial research needed

1 = *mitigation completed and understood*
2 = *mitigation available but not validated*
3 = *risk partially mitigated but very focused and directed research needed to lower risk*
4 = *risk partially mitigated but substantial research needed to lower risk*
5 = *no mitigation available and additional substantial research needed*

A-2 Risk Data Sheets

1.0 Advanced Life Support

Risk Data Sheet

Risk number	1
Discipline Area	Advanced Life Support
Risk title	Inability to maintain acceptable atmosphere in habitable areas
Contributing risk factors	remoteness, crew health/susceptibility to degree of system closure
Risk description	Inability to control excessive atmosphere concentration CO2 and O2, and trace contaminants in habitable areas; excessive airborne chemical pollutants, including microbial contaminants (leaks, fires microbial degradation of biological wastes, formaldehyde, ethylene glycol, freon spills or altered virulence or antibiotic susceptibility of microorganism)
Risk Rank (within Discipline Area)	1
Risk Type (across risks)	II
Current risk mitigation status	4
Specific current countermeasure(s) or mitigation(s)	Current sensors, test equipment and analysis equipment, some filtration, venting, LiOH backup compression gas storage, emergency personal breathing systems
Specific projected countermeasure(s) or mitigation(s)	Electrolysis, absorption systems, oxidation, emergency personal breathing systems, real time analysis, higher fidelity sensors, "smart" control systems, insitu resources
Relationship to risks within Discipline Area and to other Discipline Areas	Environmental health
Critical Questions (priority):	1.01 What is the best method for controlling total atmospheric pressure, O2 and CO2 partial pressure? (2)
	1.02 What is the best CO2 adsorbing material and/or mechanism? (2)
	1.03 What is the best way to recover the O2 from the CO2? (2)
	1.04 What is the best method to control trace gas contaminants? (2)
	1.05 Are sensors available to provide environmental data? (3)
	1.06 Are sensors available to monitor performance? (3)
	1.07 What is the best monitoring and control system? (3)
Important References:	Spaceflight Life Support and Biospherics, Eckart, 1996
	Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA, 1994
	Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington:DC., 1997

Risk Data Sheet

Risk number	2
Discipline Area	Advanced Life Support
Risk title	Inability to provide and recover potable water
Contributing risk factors	Remoteness, crew health/susceptibility to degree of system closure
Risk description	Inability to provide and recover potable water from human-generated waste waters. Risk is failure to provide and recover water from human-generated waste waters reliably with physical properties intact (i.e., taste, odor), and with minimum power, mass, volume, and consumables; chemical and microbial contamination of spacecraft water, or altered virulence or antibiotic susceptibility of microorganisms
Risk Rank (within Discipline Area)	2
Risk Type (across risks)	II
Current risk mitigation status	4
Specific current countermeasure(s) or mitigation(s)	Fuel cells, heat treatment, biocide additives, reprocessing, dumping
Specific projected countermeasure(s) or mitigation(s)	Fuel cells, heat treatment, biocide additives, reprocessing, dumping; insitu resources, improved sensors and measuring devices, integrated ALS systems with plants and condensate systems
Relationship to other risks within Discipline Area and to other Discipline Areas	Environmental health
Critical Questions (Priority):	1.16 What is the best method for supplying potable water to use points? (3)
	1.17 What waste water collection and transport mechanisms are best? (3)
	1.18 What methods are best for removal of organic and inorganic contaminants in waste water (physiochemical, biological)? (2)
	1.19 What is the best method to add a residual biocide? (3)
	1.20 What is the best way to store and maintain potability of recycled water? (2)
	1.21 What methods (sensors) are available to measure water quality parameters? (3)
	1.22 What is the best monitoring and control system? (3)
Important References:	Spaceflight Life Support and Biospherics, Eckart, 1996
	Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA, 1994
	Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington:DC, 1997

Risk Data Sheet

Risk number	4
Discipline Area	Advanced Life Support
Risk title	Inability to maintain thermal balance in habitable areas
Contributing risk factors	Sources of heat from other elements of the mission; orientation of the vehicle during flight; orientation of vehicle and/or habitat on planetary surface; location on planetary surface; planetary environment (temperature ranges & extremes, dust, seasonal variations, etc.); use or availability of local planetary resources
Risk description	Inability to acquire, transport, and reject waste heat from life support systems reliably and efficiently with minimum power, mass and volume. Capability is crucial to enabling extended human exploration of space.
Risk Rank (within Discipline Area)	3
Risk Type (across risks)	II
Current risk mitigation status	5
Specific current countermeasure(s) or mitigation(s)	condensing heat exchangers
Specific projected countermeasure(s) or mitigation(s)	active thermal control system using membranes
Relationship to other risks within Discipline Area and to other Discipline Areas	Environmental health; human performance
Critical Questions (priority):	1.23 What is the best thermal working fluid for the thermal control components in habitable areas? (3)
	1.24 What materials and designs are best used to acquire waste heat (condensing heat exchangers, coldplates, etc.)? (3)
	1.25 What material and designs are best for the thermal transport components (pumps, phase separators, etc.)? (3)
	1.26 What materials and designs are best for the thermal rejection components (radiators for use on vehicles vs moon and Mars)? (2)
	1.27 What is the best way to control humidity? (3)
	1.28 Are sensors available to provide environmental data? (3)
	1.29 Are sensors available to monitor performance of the thermal system? (3)
	1.30 What is the best monitoring and control system? (3)
Important References	Spaceflight Life Support and Biospherics, Eckart, 1996
	Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA, 1994
	Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington: DC, 1997

Risk Data Sheet

Risk number	5
Discipline Area	Advanced Life Support
Risk title	Inability to adequately process solid wastes
Contributing risk factors	Not specified
Risk description	Inability to adequately process solid wastes reliably with minimum power, mass, volume, and consumable. Capability is crucial to enabling extended human exploration of space & self-efficiency (i.e., independence from Earth re-supply)
Risk Rank (within Discipline Area)	3
Risk Type (across risks)	II
Current risk mitigation status	4
Specific current countermeasure(s) or mitigation(s)	Storage, freeze drying
Specific projected countermeasure(s) or mitigation(s)	Storage, freeze drying; incineration, bio-oxidation, methods for re-use
Relationship to other risks within Discipline Area and to other Discipline Areas	Environmental health; Human performance
Critical Questions:	1.31 What is the best method to process solid wastes for storage and/or disposal? (2)
	1.32 What is the best method to process solid wastes to recover resources? (2)
	1.33 What constraints should be imposed on materials such as packaging, paper, etc.? (3)
	1.34 How should solid waste streams be separated (edible plant biomass, trash and paper, feces, etc.)? (3)
	1.35 What is the best methodology for dealing with residuals? (2)
	1.36 Are sensors available to monitor performance? (3)
	1.37 What is the best monitoring and control system? (3)
Important References:	Spaceflight Life Support and Biospherics, Eckart, 1996
	Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA, 1994
	Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington:DC., 1997

Risk Data Sheet

Risk number	53
Discipline Area	Advanced Life Support
Risk title	Inadequate nutrition (malnutrition) due to inability to provide and maintain a bioregenerative system
Contributing risk factors	Not specified
Risk description	Inability to provide adequate food in terms of human nutrition requirements as specified by NASA medical sciences reliably (including use of higher plants). Nutritional requirements for space include fluids, macronutrients, micronutrients, compounds or elements that may be required and compounds that may affect health status such as cholesterol, fatty acids, proportion of energy substrates, fiber, non-nutritive factors such as carotenoids, etc. Inability to provide adequate food in terms of human
Risk Rank (within Discipline Area)	3
Risk Type (across risks)	II
Current risk mitigation status	4
Specific current countermeasure(s) or mitigation(s)	Stored and freeze-dried foods, stored fluids, fuel cell water, vitamin supplements
Specific projected countermeasure(s) or mitigation(s)	Stored and freeze-dried foods, stored fluids, fuel cell water, vitamin supplements; edible plant production and processing, water re-cycling
Relationship to other risks within Discipline Area and to other Discipline Areas	Food and nutrition, Radiation effects
Critical Questions:	1.09 What is the best method to grow plants with established plant production requirements including light, water, gas, gas composition and pressure, trace gas contaminants, nutrient status, mechanical support, freedom from diseases and insects? (2)
	1.10 What species and cultivars should be used to optimize production and meet nutritional requirements? (2)
	1.11 What mechanized or automated systems for planting, harvesting, and monitoring and control are required? (2)
	1.12 What methods are best to maintain genetic integrity? (2)
	1.13 What are the interfaces with the air revitalization and water recovery systems? (3)
	1.14 What processing and storage of plant products must be accommodated? (2)
	1.46 What percentage of crew food needs should be attributed to ALS plant products? (1)
	1.47 What processing processes and hardware will be required to convert ALS plant products into edible supplements to stowed food? (1)
	1.15 What are the effects of radiation on plant growth? (1)
Important References:	Spaceflight Life Support and Biospherics, Eckart, 1996
	Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems, NASA, 1994
	Advanced Technology of Human Support in Space, Committee on Advanced Technology for Human Support in Space, Aeronautics and Space Engineering Board, National Research Council, National Academy Press, Washington:DC., 1977 , 1997

Risk Data Sheet

Risk number	6
Discipline Area	Advanced Life Support
Risk title	Inadequate stowage and disposal facilities for solid and liquid trash generated during mission
Contributing risk factors	Not specified
Risk description	Provide a system for adequately storing, neutralizing, compacting, & potentially recycling trash generated (including clothing) throughout the mission, reliably and efficiently with minimum power, mass and volume
Risk Rank (within Discipline Area)	4
Risk Type (across risks)	II
Current risk mitigation status	4
Specific current countermeasure(s) or mitigation(s)	Stowage, dunping, venting
Specific projected countermeasure(s) or mitigation(s)	Recycling, innovative stowage options
Relationship to other risks within Discipline Area and to other Discipline Areas	Human performance; Environmental health
Critical Questions:	1.44 Could any of the solid waste be recycled in such a way as to provide building material for habitability features needed in subsequent phases of the mission? (3)
Important References:	

Risk Data Sheet

Risk number	3
Discipline Area	Advanced Life Support
Risk title	Inadequate supplies (including maintenance, emergency provisions, and edible food)
Contributing risk factors	Not specified
Risk description	Inadequate provisions to handle inflight maintenance requirements and the inability to provide edible food due to limited food packaging technology, reliably, efficiently, and with minimum power, mass, and volume
Risk Rank (within Discipline Area)	2
Risk Type (across risks)	II
Current risk mitigation status	4
Specific current countermeasure(s) or mitigation(s)	Mission abort, re-supply
Specific projected countermeasure(s) or mitigation(s)	Advanced food packaging and storage, food production, re-supply, recycling, insitu resources
Relationship to other risks within Discipline Area and to other Discipline Areas	radiation effects
Critical Questions:	1.45 What storm shelter supplies must be provided to allow the crew to survive radiation threats requiring retreat into save areas for prolonged time periods? (3)
Important References:	Not Specified

2.0 Bone Loss

Risk Data Sheet

Risk number	9
Discipline Area	Bone Loss
Risk title	Acceleration of age-related osteoporosis
Contributing risk factors	age, recovery rate postflight, gender, baseline BMD, diet
Risk description	Failure to recover bone lost during mission coupled with age-related bone loss can lead to osteoporotic fractures at a younger age. Important for long duration missions for crew health and for designing rehabilitation strategies.
Risk Ranking (within Discipline Area)	1
Risk Type (across risks)	I
Current risk mitigation status	3
Specific current countermeasure(s) or mitigation(s)	Crew Selection; Exercise Regime
Specific projected countermeasure(s) or mitigation(s)	Crew Screening and Selection for "at Risk" Individuals; Hormone Replacement Therapy; Exercise and Fitness Regimens; Rehabilitation Strategies; Spacesuit Design; Diagnostic Tools (Note: Should know enough by 2005 to avoid selecting those individuals with highest risk for acute acceleration of bone loss during a Mars mission.)
Relationship to other risks within Discipline Area and to other Discipline Areas	Muscle Alterations and Atrophy; Fracture and Impaired Fracture Healing (Bone Loss); Injury to Connective Tissue, Joint Cartilage, Disc Rupture; Clinical Capabilities
Critical Questions:	2.03 Will bone mass loss (e.g., 1- 1.5% per month) continue unabated for missions greater than 6 months in duration, or will it eventually plateau at some time consistent with absolute bone mineral density? Is this "minimum BMD" site-specific or consistent over numerous skeletal sites? (1)
	2.09 What are the most important predictors for bone loss during prolonged exposure to hypogravity, especially with reference to ethnicity, gender, age, baseline BMD, bone morphometry (e.g., femoral neck length)? (1)
	2.19 Is bone loss reversible and within what time frame: Can geometry and architecture return to baseline as well as BMD? (1)
	2.20 What is the most optimal rehabilitation regimen upon return to normal gravity to maximize return to baseline BMD and bone morphometry, especially given that muscle strength will recover more quickly than will bone strength? (2)
	2.25 Can the pattern of reversibility be correlated with serum or urine biomarkers of bone turnover? (3)
	2.26 What treatment regimen in returning crew with bone loss will most effectively restore bone mass, geometry and strength to their preflight integrity? (2)
Important References:	NASA Countermeasures Final Report (1997)
Current Tasks:	Sub-regional Assessment of Bone Loss in the Axial Skeleton in Long Term Spaceflight (Lang, TF - 1998) Critical Question (2.03)
	Compact, High Precision, Multiple Projection DEXA Scanner (Charles, J. 1998) Critical Question (2.14)

Risk Data Sheet

Risk number	10
Discipline Area	Bone Loss
Risk title	Fracture (traumatic, stress, avulsion) and impaired fracture healing
Contributing risk factors	Poor nutrition, decreased muscle mass, muscle/bone strength imbalance, endocrine dysfunction can aggravate this
Risk description	Increased risk of fracture (traumatic, stress, avulsion) upon return to activity in 1/3 to 1 g due to hypogravity-induced bone loss.
Risk Rank (within Discipline Area)	2
Risk Type (across risks)	II
Current risk mitigation status	3
Specific current countermeasure(s) or risk mitigation strategies	Exercise, medications, nutrition
Specific projected cm(s) or risk mitigation strategies	Resistive exercise regimes, medications, preflight fitness, spacesuit design to minimize fracture risk
Relationship to other risks within Discipline Area and to other Discipline Areas	Food and nutrition, muscle alterations and atrophy
Critical Questions:	2.01 What is the relative risk of sustaining a traumatic and/or stress fracture for a given decrement in bone mineral density or bone geometry in an astronaut-equivalent population (i.e., 30-60 year old healthy men and women) who are also physically active? (1)
	2.02 What are the mechanical loads imposed on important skeletal sites in the Martian environment of 1/3 g, given anticipated work tasks? (1)
	2.03 Will bone mass loss (e.g., 1-1.5% per month) continue unabated for missions greater than 6 months in duration, or will it eventually plateau at some time consistent with absolute bone mineral density? Is this "minimum BMD" site-specific or consistent over numerous skeletal sites? (2)
	2.04 What localized bone changes at tendon sites would contribute to increased risk of avulsion fractures (i.e., how much disparity between bone & muscle strength can be incurred without increased risk of avulsion fracture)? (2)
	2.05 Is there an additive or synergistic effect of estrogen deficiency (as in post-menopausal or amenorrheic women) and prolonged exposure to hypogravity? (4)
	2.06 What pharmacological agents will most effectively minimize the decrease in bone mass with hypogravity? Are anabolic regimes as well as anti-resorptive agents required? (1)
	2.07 What are the specifics of the optimal exercise regimen to be followed during exposure to hypogravity to minimize decreases in bone mass with regard to workout duration, intensity, frequency? Is impact loading an essential element? If so, how can it be produced in hypogravity? (1)
	2.08 Is there an optimal combination of exercise (an anabolic stimulus) and a pharmacological countermeasure (anti-resorptive) to minimize decrements in bone mass in hypogravity? (1)
	2.09 What are the most important predictors for bone loss during prolonged exposure to hypogravity, especially with reference to ethnicity, gender, age, baseline BMD, bone morphometry (e.g., femoral neck length)?
	2.10 Does hypogravity exposure change the nutritional requirements for optimal bone health (e.g., does calcium absorption decrease)? (1)
	2.11a Does prolonged exposure to hypogravity lead to impaired healing of fractures? (1)
	2.11b Does prolonged exposure to hypogravity lead to result in changes in structural or functional integrity of vertebral bone? (2)
	2.12 What are the signal transduction pathways allowing bone cells to sense gravity and loading on bone? (2)
	2.13 Does hypogravity affect the size, viability, or differentiation of precursor bone cell populations? (2)
	2.14 What practical diagnostic tools can be utilized during multi-year missions to monitor and quantify changes in bone mass and strength (e.g., biochemical markers, DEXA, ultrasound)? (2)
	2.15 Are there important other mechanisms for bone loss with hypogravity that are critical to developing effective countermeasures (e.g., fluid shifts with altered hydrostatic pressure, changes in blood flow, immune system alterations)? (2)
	2.24 Which animal models will be most effective in defining the risk of fracture and impaired healing of fractures with prolonged exposure to microgravity? (2)
	2.26 What treatment regimen in returning crew with bone loss will most effectively restore bone mass, geometry and strength to their preflight integrity? (2)
Key References	*Not specified*

Risk Data Sheet

Risk number	11
Discipline Area	Bone Loss
Risk title	Injury to soft connective tissue, joint cartilage, and intervertebral disc rupture with or without neurological complications
Contributing risk factors	decreased muscle strength, decreased loads on muscle and connective tissue, muscle atrophy and bone/mineral loss, biomechanical disturbances
Risk description	Fascia, tendon and ligament overuse or traumatic injury, joint dysfunction upon return to normal/partial gravity. Hypogravity changes to intervertebral discs may increase risk of rupture, with attendant back pain, possible neurological complications.
Risk Rank (within Discipline Area)	3
Risk Type (across risks))	III
Risk mitigation status	5
Specific current countermeasure(s) or mitigation(s)	None or not known
Specific projected countermeasure(s) or mitigation(s)	Exercise protocols, suit design with protection for joints/soft tissue
Relationship to other risks within Discipline Area and to other Discipline Areas	Neurovestibular adaptations, space medicine
Critical Questions:	2.17 What is the incidence of soft connective tissue injury and pain during recovery after prolonged hypogravity or bed rest? (Use pre- and postflight analyses of MRI scan of spine and extremities and postflight follow-up studies over six months to one year.) (1)
	2.18 What countermeasures can reduce the incidence of soft connective tissue injury and pain during recovery after prolonged hypogravity or bed rest? (1)
Important References:	Not specified

Risk Data Sheet

Risk number	12
Discipline Area	Bone Loss
Risk title	Renal stone formation
Contributing risk factors	Inflight overloaded schedule, motion sickness on return to 1 g, decreased skeletal loads inflight, hypercalcuria risk throughout flight, decreased urine volume, increased bone resorption
Risk description	Urine calcium concentration is increased due to increased bone resorption during hypogravity and to decreased urine volume during periods of dehydration.
Risk Rank (within Discipline Area)	4
Risk Type (across risks)	III
Current risk mitigation status	2
Specific current cm (s) or risk mitigations	exercise, fluid loading, increased bone resorption during hypogravity and to decreased urine volume during periods of dehydration
Specific projected cm(s) or risk mitigations	IV fluids, dietary controls, LBNP, preflight adaptation training
Relationship to other risks within Discipline Area and to other Discipline Areas	food and nutrition, cardiovascular alterations
Critical Questions:	2.05 Is there an additive or synergistic effect of estrogen deficiency (as in post-menopausal or amenorrheic women) and prolonged exposure to hypogravity? (4)
	2.09 What are the most important predictors for bone loss during prolonged exposure to hypogravity, especially with reference to ethnicity, gender, age, baseline BMD, bone morphometry (e.g., femoral neck length)? (1)
	2.10 Does hypogravity exposure change the nutritional requirements for optimal bone health (e.g., does calcium absorption decrease)? (1)
	2.13 Does hypogravity affect the size, viability, or differentiation of precursor bone cell populations? (2)
	2.06 What pharmacological agents will most effectively minimize the decrease in bone mass with hypogravity? Are anabolic regimes as well as anti-resorptive agents required? (1)
	2.07 What are the specifics of the optimal exercise regimen to be followed during exposure to hypogravity to minimize decreases in bone mass with regard to workout duration, intensity, frequency? Is impact loading an essential element? If so, how can this be produced in hypogravity? (1)
	2.08 Is there an optimal combination of exercise (an anabolic stimulus) and a pharmacological countermeasure (anti-resorptive) to minimize decrements in bone mass in hypogravity? (1)
	2.21 Does existing data allow prediction of stone risk? (3)
Important References:	Not specified

3.0 Cardiovascular Alterations

Risk Data Sheet

Risk number	13
Discipline Area	Cardiovascular Alterations
Risk title	Occurrence of serious cardiac dysrhythmias
Contributing risk factors	Fluid and Electrolyte Imbalance, Diminished Cardiac Mass
Risk description	Serious cardiac rhythm disturbances including ventricular tachycardia have been recorded on several occasions during spaceflight. Cardiac dysrhythmias pose a potentially lethal risk during long duration spaceflight.
Risk Rank (within Discipline Area)	1
Risk Type (across risks)	II
Current risk mitigation status	5
Specific current countermeasure(s) or mitigation(s)	None
Specific projected countermeasure(s) or mitigation(s)	Electrical Cardioversion, Artificial G Exposure, Anti-arrhythmic pharmaceuticals
Relationship to other risks within Discipline Area and to other Discipline Areas	Diminished Cardiac Function; Clinical Capabilities
Critical Questions:	3.01 Does spaceflight increase susceptibility to serious cardiac dysrhythmias and, if so, what are the mechanisms? (1)
	3.02 Can risk of serious cardiac dysrhythmias be predicted for individual crewmembers? (1)
	3.03 What countermeasures may prevent or reduce the occurrence of serious cardiac dysrhythmias during long term spaceflight? (2)
	3.04 Can serious cardiac dysrhythmias be effectively diagnosed and treated during spaceflight? (2)
Important References	Charles JB, Bungo MW, Fortner GW. Cardiopulmonary Function. In: Nicogossian A, Huntoon C. Pool S., and (editors). Space Physiology and Medicine. 3rd ed. Philadelphia, PA: Lea & Febiger, 286-304, 1994.
	Hawkins WR, Zieglschmid JF. Clinical Aspects of Crew Health. In: Biomedical Results of Apollo (NASA SP-368). Johnston RS Dietlein LF, Berry CA, editors. Washington, DC: U.S. Government Printing Office, 43-81, 1975.
	Smith RF, Stanton K, Stoop D, Brown D, Januez W, King P. Vectorcardiographic Changes During Extended Spaceflight (M093): Observations at Rest and During Exercise. In: Biomedical Results of Skylab (NASA SP-377). Johnston RS and Dietlein LF, editors. Washington, DC: NASA 339-350, 1977.

Risk Data Sheet

Risk number	14
Discipline Area	Cardiovascular Alterations
Risk title	Impaired cardiovascular response to orthostatic stress
Contributing risk factors	plasma fluid shift, fluid intake, altered hemodynamic regulation, changes in vascular compliance
Risk description	Following exposure to microgravity, upright posture results in the inability to maintain adequate arterial pressure and cerebral perfusion (orthostatic or postural hypotension). This may result in syncope (loss of consciousness) during re-entry or egress. Severity increases with duration of exposure to microgravity.
Risk Rank (within Discipline Area)	1
Risk Type (across risks)	II
Current risk mitigation status	5
Specific current countermeasure(s) or mitigation(s)	g suit; fluid loading
Specific projected countermeasure(s) or mitigation(s)	Oral alpha agonist drugs, artificial G exposure, drugs that affect red blood cell mass, drugs and/or equipment such as peripheral tourniquets that will increase plasma volume
Relationship to other risks (within Discipline Area and to other Discipline Areas)	Clinical Capabilities, Neurovestibular Adaptation, Diminished Cardiac Function
Critical Questions:	3.05 What are the physiological and environmental factors by which spaceflight decreases orthostatic tolerance? (1)
	3.06 How does duration of spaceflight affect the severity and time course of orthostatic intolerance, and what are the mechanisms? (1)
	3.07 Is orthostatic intolerance likely to develop on the surface of Mars? (1)
	3.08 Can spaceflight-induced orthostatic intolerance be predicted for individual crewmembers? (1)
	3.09 What countermeasures can be developed to overcome or prevent orthostatic intolerance? (1)
Important References	*(1) Task Force Final Report on Countermeasures, NASA, Space Life Sciences, May 1997*
	(2) Space Medicine Monitoring and Countermeasures Project Report, NASA, Johnson Space Center, October, 1997
	(3) Charles JB, Bungo MW, Fortner GW. Cardiopulmonary Function. In: Nicogossian A, Huntoon C. Pool S., editors. Space Physiology and Medicine. 3rd ed. Philadelphia, PA: Lea & Febiger, 286-304, 1994.

Risk Data Sheet

Risk number	15
Discipline Area	Cardiovascular Alterations
Risk title	Diminished cardiac function
Contributing risk factors	Reduction of stress on heart over prolonged period in weightlessness
Risk description	Short duration spaceflight has been associated with a decrease in cardiac mass. Long duration spaceflight may result in greater decrease in cardiac mass and additional alterations which may diminish cardiac function and could be irreversible.
Risk Rank (within Discipline Area)	2
Risk Type (across risks)	III
Current risk mitigation status	5
Specific current countermeasure(s) or mitigation(s)	None
Specific projected countermeasure(s) or mitigation(s)	Drugs that affect cardiac mass and function, artificial G exposure with exercise (bicycle centrifuge).
Relationship to other risks within Discipline Area or other Discipline Areas	Clinical Capabilities, Impaired Cardiovascular Response to Exercise Stress
Critical Questions:	3.17 Does long duration spaceflight lead to diminished cardiac function and, if so, what are the mechanisms and is the process reversible? (2)
	3.18 What is the extent of reduction in cardiac mass associated with long duration spaceflight and what are the mechanisms? (2)
	3.19 Can susceptibility to reduced cardiac function be predicted for individual crewmembers? (2)
	3.20 What countermeasures may be effective in mitigating the risk? (2)
Important References:	Blomqvist CG, Lane LD, Wright SJ, et al. Cardiovascular regulation at microgravity. In: *Scientific Results of the German Spacelab Mission D-2, Proceedings of Symposium at Norderney*, Sahm PR, Keller MH, and Schiewe B, editors. Wissenschaftliche Projektfuhrung D2, RWTH Aachen, Care of DLR, Koln, pp. 688-690.

Risk Data Sheet

Risk number	16
Discipline Area	Cardiovascular Alterations
Risk title	Manifestation of previously asymptomatic cardiovascular disease
Contributing risk factors	Lack of sufficiently sensitive screening measures
Risk description	There have been cardiac events during spaceflight that have impacted mission objectives. Spaceflight may aggravate underlying cardiovascular disease, such as coronary artery disease. Such problem may become more prevalent as crewmembers are drawn from populations at higher risk for cardiovascular disease (e.g., on the basis of age, gender, and diversity).
Risk Rank (within Discipline Area)	3
Risk Type (across risks)	III
Current risk mitigation status	5
Specific current countermeasure(s) or mitigation(s)	Screening with treadmill test and 2D surface echocardiogram
Specific projected countermeasure(s) or mitigation(s)	Incorporation of more sensitive and specific screening methods based on demographic profile.
Relationship to other risks within Discipline Area and to other Discipline Areas	Clinical Capabilities
Critical Questions:	3.14 Are cardiovascular diseases are likely to be aggravated by spaceflight and, if so, which ones and by what mechanisms? (1)
	3.15 What improved screening methods might identify crewmembers with underlying cardiovascular disease which may be aggravated by spaceflight? (1)
	3.16 What countermeasures may be effective in mitigating the risk? (2)
Important References:	Not specified

Risk Data Sheet

Risk number	17
Discipline Area	Cardiovascular Alterations
Risk title	Impaired cardiovascular response to exercise stress
Contributing risk factors	Diminished Cardiac Function, decreased blood volume
Risk description	Spaceflight results in decreased aerobic exercise capacity upon re-entry into a gravitational field, resulting in impaired ability to perform strenuous tasks.
Risk Rank (within Discipline Area)	4
Risk Type (across risks)	III
Current risk mitigation status	3
Specific current countermeasure(s) or mitigation(s)	Exercise in flight
Specific projected countermeasures or risk mitigations	Exercise in flight coupled with artificial G exposure (bicycle centrifuge), Drugs that affect cardiac mass and function.
Relationship to other risks within Discipline Area and to other Discipline Areas	Muscle Alterations and Atrophy, Clinical Capabilities, Diminished Cardiac Function
Critical Questions:	3.10 What are the physiological and environmental factors by which spaceflight decreases aerobic exercise capacity? (1)
	3.11 How does duration of spaceflight affect the severity of limitation of exercise capacity? (1)
	3.12 Can aerobic exercise capacity limitation be predicted for individual crewmembers? (2)
	3.13 What countermeasures can be developed to overcome aerobic exercise capacity limitation? (2)
Important References	Shykoff BE, Farhi LE, Olszowka AJ, et al. Cardiovascular response to submaximal exercise in sustained microgravity. J. Appl. Physiol., 81:26-32, 1996.
	Michel EL, Rummel JA, Sawin CF, Buderer MC Lem JD. Results of Skylab Medical Experiment M171: metabolic activity. In: *Biomedical Results from Skylab*, Johnston RS and Dietlein LF, editors. Washington, DC: National Aeronautics and Space Administration, 1977, pp. 372-387.
	Rummel JA, Sawin CF, Michel EL. Exercise response. In: *Biomedical Results of Apollo*, Johnston RS, Dietlein LF, and Berry CF, editors. Washington DC: National Aeronautics and Space Administration, 1975, pp. 265-275.

4.0 Environmental Health

Risk Data Sheet

Risk number	51
Discipline Area	Environmental Health
Risk title	Inability to maintain acceptable atmosphere in habitable areas due to environmental health contaminants
Contributing Risk factors	remoteness, crew health/susceptibility to degree of system closure
Risk description	Inability to control excessive atmosphere CO2 and O2 concentration, and trace contaminants in habitable areas; excessive airborne chemical pollutants, including microbial contaminants (including leaks, fires microbial degradation of biological wastes, formaldehyde, ethylene glycol, freon spills); or altered virulence or antibiotic susceptibility of microorganisms
Risk Rank (within Discipline Area)	1
Risk Type (across risks)	II
Current risk mitigation status	4
Specific current countermeasure(s) or mitigation(s)	Not specified
Specific projected countermeasure(s) or mitigation(s)	Not specified
Relationship to other risks within Discipline Area and to other Discipline Areas	Advanced Life Support; Immunology, Infection and Hematology
Critical Questions:	4.01 What are the most likely sources of severe air or water pollution and how can these sources be controlled over long periods of time? (1)
	4.02 What are the acceptable numbers and kinds of microorganisms in air, water, food, and surfaces? (1)
	4.03 What resources are required to manage plausible environmental risks during long and remote missions? (1)
	4.04 How can traditional limited-time exposure and human toxicological data be used to predict acceptable values for inhalation and ingestion exposures to single chemicals and/or to mixtures? (2)
	4.05 What approaches to setting exposure standards may be used when insufficient data are available to allow prediction of acceptable exposure levels? (1)
	4.06 How much risk do materials that condense inside the spacecraft pose to the environmental health? (2)
	4.07 What impact do spaceflight-induced biological, physiological, & immunological changes have on the susceptibility of crewmembers to toxic substances in the air and water? (2)
	4.08 What are the effects of exposure to ultrafine and larger (respirable and non-respirable) particles (e.g. Martian dust) on crew health, safety, and performance? (2)
	4.11 What are the interactions of microbes, chemicals and plants in a CELSS on air and water quality? (2)
	4.12 What are the effects of the space environment on microbial interactions with space systems and humans? (2)
	4.13 How rapidly can acceptable air quality be recovered after a severe pollution condition and what is the effect on humidity condensate and the water recovery system? (2)
	4.15 How can automated real-time systems be used to monitor air and water quality for a Mars mission, and how will the crew interpret the results without ground support? (1)
Important References:	Pool, S.L. Ethylene Glycol Treatise. NASA/JSC Memorandum SD2-97-542, September 15, 1997
	Nicogossian, A.E. et al., Crew Health in The Apollo-Soyuz Test Project Medical Report, NASA SP-411, 1977
	Huntoon, C.L., Toxicological Analysis of STS-40 Atmosphere, NASA/JSC Memorandum, SD4/01,93-251, July 6, 1991; Toxicological Analysis of STS-55 Atmosphere, NASA/JSC Memorandum SD4-93-251, July 6, 1993
	James, J.T., Toxicological Assessment of Air Samples Taken after the Oxygen-Generator Fire on Mir, NASA/JSC Memorandum SD2-97-513, April 10,1997
	James, J.T., Toxicological Assessment of Air Contaminants during the Mir 19 Expedition, 19??

Risk Data Sheet

Risk number	52
Discipline Area	Environmental Health
Risk title	Inability to provide and recover potable water due to environmental health contaminants
Contributing Risk factors	remoteness, crew health/susceptibility to degree of system closure
Risk description	Inability to provide and recover potable water from human-generated waste waters. Risk is failure to provide and recover water from human-generated waste waters reliably with physical properties intact (i.e., taste, odor), and with minimum power, mass, volume, and consumables; Chemical and microbial contamination of spacecraft water, and altered virulence or antibiotic susceptibility of microorganisms
Risk Rank (within Discipline Area)	2
Risk Type (across risks)	II
Current risk mitigation status	5
Specific current countermeasure(s) or mitigation(s)	Not specified
Specific projected countermeasure(s) or mitigation(s)	Not specified
Relationship to other risks within Discipline Area and to other Discipline Areas	Advanced Life Support; Immunology, Infection and Hematology
Critical Questions:	4.01 What are the most likely sources of severe air or water pollution and how can these sources be controlled over long periods of time? (1)
	4.02 What are the acceptable numbers and kinds of microorganisms in air, water, food, and surfaces? (1)
	4.03 What resources are required to manage plausible environmental risks during long and remote missions? (1)
	4.04 How can traditional limited-time exposure and human toxicological data be used to predict acceptable values for inhalation and ingestion exposures to single chemicals and/or to mixtures? (2)
	4.05 What approaches to setting exposure standards may be used when insufficient data are available to allow prediction of acceptable exposure levels? (2)
	4.07 What impact do spaceflight-induced biological, physiological, & immunological changes have on the susceptibility of crewmembers to toxic substances in the air and water? (2)
	4.11 What are the interactions of microbes, chemicals and plants in a CELSS on air and water quality? (2)
	4.12 What are the effects of the space environment on microbial interactions with space systems and humans? (2)
	4.13 How rapidly can acceptable air quality be recovered after a severe pollution condition and what is the effect on humidity condensate and the water recovery system? (2)
	4.15 How can automated real-time systems be used to monitor air and water quality for a Mars mission, and how will the crew interpret the results without ground support? (1)
Important References:	Carter, D.L., Phase III Integrated Water Recovery Testing as MSFC: ISS Recipient Mode Test Results and Lessons Learned. ICES Paper, No. 972375, July 1997
	Pierre et al., Collection and Chemical Analysis of Potable Water and Humidity Condensate from the Mir Space Station. ICES Paper No., 972462, July 1997

Risk Data Sheet

Risk number	50
Discipline Area	Environmental Health
Risk title	Allergies and Hypersensitivity Reactions from Exposure to the Enclosed Spacecraft and Other Environmental Factors
Contributing Risk factors	chemically sensitive individuals or altered immune responses, impaired pulmonary capacity
Risk description	Allergic hypersensitivity caused by exposure to environmental agents (chemical and microbial)
Risk Rank (within Discipline Area)	3
Risk Type (across risks)	II
Current risk mitigation status	3
Specific current countermeasure(s) or mitigation(s)	Limited medical screening for sensitivities
Specific projected countermeasure(s) or mitigation(s)	Expanded medical screening for hypersensitivities
Relationship to other risks within Discipline Area and to other Discipline Areas	Immunology, infection and hematology
Critical Questions:	4.07 What impact do spaceflight-induced biological, physiological, & immunological changes have on the susceptibility of crewmembers to toxic substances in the air and water? (2)
	4.08 What are the effects of exposure to ultrafine and larger (respirable and non-respirable) particles (e.g., Martian dust) on crew health, safety and performance? (2)
	4.14 How will persons who are hypersensitive to chemicals and microbes in air and water be identified? (2)
	4.16 If hypersensitivity develops during spaceflight, how will individuals be treated? (1)
Important References:	Not specified

5.0 Food and Nutrition

Risk Data Sheet

Risk number	*7*
Discipline Area	Food and Nutrition
Risk title	Inadequate Nutrition (Malnutrition)
Contributing risk factors	Inadequate nutritional requirements, inability to provide food, improper food intake, stress, countermeasures induced-alterations in nutrient requirements
Risk description	Inability to provide adequate food in terms of human nutrition requirements as specified by NASA medical sciences reliably (including use of higher plants). Nutritional requirements for space include fluids, macronutrients, micronutrients, compounds or elements that may be required and compounds that may affect health status such as cholesterol, fatty acids, proportion of energy substrates, fiber, non-nutritive factors such as carotenoids, etc. Requirements must take into account any of the changes in the sensorisystem that might influence taste and smell and the role of countermeasures induced-alterations on nutrient requirements. All U.S. space crews to date have experienced nutritional deficiencies.
Risk Rank (within Discipline Area)	1
Risk Type (across risks)	II
Current risk mitigation status	4
Specific current countermeasure(s) or mitigation(s)	Nutrition requirements based upon extrapolation , infrequent nutrient intake monitoring
Specific projected countermeasure(s) or mitigation(s)	Complete inflight nutrient assessment, enhanced food system, improved countermeasures, assessment of food psychosocial importance
Relationship to other risks within Discipline Area and other Discipline Areas	unsafe food system, loss of muscle strength, bone fractures, psychogenic or chronogenic illness
Critical Questions (priority):	5.03 What are the nutritional requirements for exploration missions, e.g. calories, protein, calcium, iron, antioxidants, iodine, vitamin D, electrolytes? (1)
	5.05 What are the psychosocial requirements of the food system? (2)
	5.08 What technology will be required to develop a viable food system? (2)
	5.09 What type(s) of food system(s) should be used? (1)
	5.07 What monitoring method should be used to assure food safety during the entire mission? (2)
	5.06 What are the sensory changes (taste, odor, etc.) that occur during spaceflight? (4)
	5.04 What are the potential impacts of countermeasures on nutritional requirements? (1)
	5.02 What are the impacts of changing gravity on the food system i.e., galley? (3)
	5.10 What are the means of monitoring nutritional status during the mission? (3)
	5.01 How much flight access is required to answer above questions? (2)
Important References	Modern Nutrition In Health and Disease, 9th edition
	NASA Johnson Space Center. Nutritional Requirements for International Space Station Missions Up To 360 Days. JSC-28038; 1996.

Risk Data Sheet

Risk number	8
Discipline Area	Food and Nutrition
Risk title	Unsafe food systems
Contributing risk factors	chemical or microbial contamination, packaging, environmental control
Risk description	Inability to provide viable food system that: meets nutritional requirements, is safe in terms of spoilage or contamination, and is consistent with crew compliance issues (e.g., changes in taste, odor, preparation, or eating preferences)
Risk Rank (within Discipline Area)	2
Risk Type (across risks)	II
Current risk mitigation status	4
Specific current countermeasure(s) or mitigation(s)	Food packaging, Hazard Analysis Critical Control Point processing, testing and evaluation
Specific projected countermeasure(s) or mitigation(s)	Development of extended shelf life food, special packaging for exploration missions, nutrient loss studies
Relationship to other risks and other Discipline Areas	malnutrition
Critical Questions (priority):	5.13 What are the effects of extended space travel on the sensory and nutrient properties of food? (2)
	5.08 What technology will be required to develop a viable food system? (1)
	5.09 What type(s) of food system(s) should be used? (1)
	5.07 What monitoring method should be used to assure food safety during the entire mission? (2)
	5.02 What are the impacts of changing gravity on the food system i.e., galley? (3)
	5.11 What type of packaging is required? (1)
	5.12 What is the risk of chemical and microbial contamination? (1)
	5.01 How much flight access is required to answer above questions? (4)
Important References	Johnston, R. S. and Dietlein, L. F. Biomedical results from Skylab. Washington DC: NASA; 1977.
	Lane, H.W., Smith, S. M., Rice, B. L. and Bourland, C. T. Nutrition in space: lessons from the past applied to the future. A J Clin Nutr 60:801S-805S; 1994.
	NASA Johnson Space Center. Nutritional Requirements for International Space Station Missions Up To 360 Days. JSC-28038; 1996.
	Smith, M.C., Heidelbaugh, N.D., Rambaut, P.C., Rapp, R.M., Wheeler, H.O., Huber, C. S., and Bourland, C. T. Biomedical Results of Apollo. U.S. Government Printing Office; 1975. Modern Nutrition In Health and Disease, 9th edition

Risk Data Sheet

Risk number	55
Discipline Area	Food and Nutrition
Risk title	Human performance failure due to nutritional deficiencies
Contributing risk factors	Malnutrition, inadequate nutrition requirements, stress, boredom
Risk description	The combination of limited food sources, physiological changes, potential stress, and other factors may have long term consequences on crew performance. Both physical and cognitive performance is related to adequate nutrition.
Risk Rank (within Discipline Area)	3
Risk Type (across risks)	II
Current risk mitigation status	3
Specific current countermeasure(s) or mitigation(s)	Palatable and acceptable food, proper knowledge of nutrition requirements
Specific projected countermeasure(s) or mitigation(s)	Refined nutritional requirements, understanding and implementation of an acceptable food system, understanding the psychological benefits of food
Relationship to other risks	malnutrition, unsafe food system
Critical Questions	5.05 What are the psychosocial requirements of the food system? (2)
	5.03 What are the nutritional requirements for exploration missions (e.g., calories, protein, calcium, iron, antioxidants, iodine, vitamin D, electrolytes)? (1)
	5.14 What is an acceptable food system? (2)
	5.01 How much flight access is required to answer above questions? (3)
Important References	NASA Johnson Space Center. Nutritional Requirements for International Space Station Missions Up To 360 Days. JSC-28038; 1996.
	Lane, H.W., Smith, S. M., Rice, B. L. and Bourland, C. T. Nutrition in space: lessons from the past applied to the future. A J Clin Nutr 60:801S-805S; 1994.
	Modern Nutrition In Health and Disease, 9th edition

Risk Data Sheet

Risk number	54
Discipline Area	Food and Nutrition
Risk title	Difficulty of rehabilitation following landing due to nutritional deficiencies
Contributing risk factors	Bone loss, renal disease, infectious disease, radiation biochemical changes, muscle wasting, decreased red blood cell mass
Risk description	Excessive time required to return to health and full duty status
Risk Rank (within Discipline Area)	4
Risk Type (across risks)	III
Current risk mitigation status	3
Specific current countermeasure(s) or mitigation(s)	NONE
Specific projected countermeasure(s) or mitigation(s)	Preflight nutritional assessment to prevent any decrements of nutritional status prior to mission, a pace flight food system that supports the maintenance of nutrition status, post flight nutritional assessment and dietary counseling by a registered dietitian. Research to determine if there are nutritional issues specifically related to spaceflight.
Relationship to other risks within Discipline Area and to other Discipline Areas	malnutrition, muscle skeletal systems, aerobic exercise.
Critical Questions	5.03 What are the nutritional requirements for exploration missions, e.g. calories, protein, calcium, iron, antioxidants, iodine, vitamin D, electrolytes? (1)
	5.15 What are the decrements in nutritional status due to long term spaceflight? (1)
	5.16 What monitoring (biochemical, anthropometric, clinical assessments) during rehabilitation is required? (3)
	5.17 What level of dietary counseling is needed for crewmembers during rehabilitation? (3)
	5.18 Are there inflight countermeasures that affect nutritional status (promote or cause decrements)? (2)
Important References	Modern Nutrition In Health and Disease, 9th edition

6.0 Human Behavior and Performance

Risk Data Sheet

Risk number	18
Discipline Area	Human Behavior and Performance
Risk title	Human Performance Failure Because of Poor Psychosocial Adaptation
Contributing risk factors	Psychosocial Adaptation
Risk description	Human performance failure due to problems associated with adapting to the space environment, interpersonal relationships, group dynamics, and pre-mission preparation.
Risk Rank (within discipline)	1
Risk Type (across risks)	I
Current risk mitigation status	4
Specific current cm(s) or mitigation(s)	1. Limited Preflight Training; 2. Inflight Psychological Support
Specific projected cm(s) or mitigation(s)	1. Monitoring & Early Detection of Adaptation problems; 2. Predictive model of adaptability to long duration missions; 3. Enhanced Preflight Training; 4. Individual and team selection for long duration missions
Relationship to other risks and to other Discipline Areas	see other Human behavior and performance risks
Critical Questions (priority):	6.01 What are the fundamental behavioral and social stressors during long duration missions that will most likely affect crew performance, both individual and team? (1) 6.02 What factors contribute to the breakdown of individual and team performance, and team coordination with mission support with regard to scheduling, prioritization of work activities and control of timelines? (1) 6.03 What behaviors, experiences, personality traits, and leadership styles in crewmembers most contribute to optimal performance? How are these factors related to team performance? (2) 6.04 What crewmember behaviors, experiences, personality traits, and leadership styles that optimize performance can be identified during the selection process and be used to select and assemble the best teams for long duration missions? (2) 6.17 What are the systems of knowledge, psychosocial support methods, attitudes, and behavior towards mission operations used by agency management, ground controllers, crewmembers and their families? How do these systems influence individual and group performance and behavior? (2)
Important References	Manzey, D., Albrecht, S., and Fassenbender, C. Psychological countermeasures for extended manned spaceflights. Acta Astonautica, Vol. 35, No. 4/5, pp.339-361, 1979
	Connors, M.M., Harrison, A.A. and Faren, R.A. Living Aloft: Human requirements for extended spaceflight. NASA SP-483, Washington, D.C., National Aeronautics and Space Administration, 1985
	Stuster, J. Bold endeavors: Lessons from polar and space exploration. Annapolis, MD. Naval Institute Press, 1996
	Lugg, D. Physiological adaptation and health of an expedition in Antarctica with comment on behavioral adaptation. Australian National Antarctic Research Expedition (ANARE) Scientific Report, Series B (4), No. 126. Canberra, Australia: ANARE, 1977
	Harrison, A.A., Clearwater, Y.A., and McKay C.A. (eds), From Antarctica to outer space: Life in Isolation and Confinement. New York: Springer-Verlag, 1991
	Miller, J. and Koblick,. Living and working in the sea. New York: Van Nostrand Reinhold Company, Inc., 1984

Risk Data Sheet

Risk number	19
Discipline Area	Human Behavior and Performance
Risk title	Human Performance Failure Because of Sleep and Circadian Rhythm Problems
Contributing risk factors	Sleep and Circadian Rhythms
Risk description	Human performance failure due to disruption of circadian phase, amplitude, period, or entrainment, and/or human performance failure due to acute or chronic degradation of sleep quality or quantity
Risk Rank (within discipline risks)	2
Risk Type (across risks)	II
Current risk mitigation status	4
Specific current cm(s) or mitigation(s)	1. Pre-flight and in-flight sleep shifting; 2. Medications; and 3. Scheduling constraints in Appendix K
Specific projected cm(s) or mitigation(s)	1. Model of performance deficit based on sleep and circadian data; 2. Sleep/circadian rhythm re-adjust tools (e.g., light treatment); 3. Individual active noise cancellation; 4. Ability to monitor sleep and circadian parameters unobtrusively
Relationship. to other risks and other Discipline Areas	See other Human Behavior and Performance risks
Critical Questions (Priority):	6.05 What are the acute and long term effects of exposure to the space environment on biological rhythmicity on sleep architecture, quantity and quality, and their relationship to performance capability? (1) 6.06 Which countermeasures or combination of behavioral and physiological countermeasures will optimally mitigate specific performance problems associated with sleep loss and circadian disturbances during a Mars mission?(1) 6.07 What are the long term effects of countermeasures employed to mitigate performance problems with sleep loss and circadian disturbances during a Mars mission? (2) 6.08 What are the best methods for inflight monitoring of the status of sleep and circadian functioning and for assessing the effects of sleep loss and circadian dysrhythmia on performance capability that are also portable and non-intrusive in the spaceflight environment? (2) 6.10 What workload schedule(s) per workday will best enhance crew performance and mitigate adverse effects of the space environment? (2) 6.21What mathematical and experimental models best predict performance problems associated with sleep-wake and work history and circadian rhythm status, and also provide guidelines for successful countermeasure strategies? (2) 6.18 What individual biological and behavioral characteristics will best predict successful adaptation to long term spaceflight of sleep and circadian physiology and the neurobehavioral performance functions they regulate? (NR)
Important References	Alyakrinski, BS., Current status of space biorhythmology. Translation: Space Biology and Aerospace Medicine. USSR, 2:1-13, 1977
	Saiki, H. and Nakaya, M. Dynamics of sleep patterns during prolonged simulated weightlessness. In: Holmquist, R. and Stickland, A., (Eds.), COSPAR Life Sciences and Space Research, Vol. XV. Oxford: Pergamon Press, pp. 224-231, 1971
	Santy, P., Kapanka, H., Davis, J., and Stewart, D. Analysis of sleep on Shuttle missions. Aviation Space Environmental Medicine, 59:1094-1097, 1988
	Kuklinski, P. and Wegmann, H.M. Biomedical investigations on payload specialist during spacelab simulation ASSESSII, Preprints Annual Scientific Meeting, Aerospace Medical Association, Washington, DC, May 14-17, pp. 338-339, 1979
	Stampi, C. Sleep and circadian rhythms in space. Journal of Clinical Psychology, 34: 518-534, 1994

Risk Data Sheet

Risk number	20
Discipline Area	Human Behavior and Performance
Risk title	Human Performance Failure Because of Human System Interface Problems and Ineffective Habitat, Equipment Design, Workload, or Inflight Information and Training Systems
Contributing risk factors	Human-Systems Interface, Habitability, Information Management and Training
Risk description	Human performance failure due to ineffective habitat and equipment design, workload, or in-flight information and training systems.
Risk Rank (within discipline risks)	3
Risk Type (across risks)	III
Current risk mitigation status	3
Specific current cm(s) or mitigation(s)	1. Selection of crew; 2. Scheduling; 3. Training for tasks; 4. Detection by self report; 5. HFE design guidelines for h/w & s/w
Specific projected cm(s) or mitigation(s)	1. In-flight critical task capabilities assessment; 2. Predictive models of workload and performance failure; 3. Decision rules or work scheduling guidelines; 4. Improved onboard training and information; 5. Upgraded HFE requirements documents
Relationship to other risks and other Discipline Areas	See other Human Behavior and Performance risks
Critical Questions (priority):	6.09 What information systems, resource management methods and tools, and communications systems architecture(s) and equipment will best support the crew's ability to operate autonomously, exchange information, learn and maintain proficiency on critical tasks, and meet the objectives of a Mars mission? How will artificial intelligence and automation be used to enable crew autonomy? (1) 6.10 What workload schedule(s) per workday will best enhance crew performance and mitigate adverse effects of the space environment? (2) 6.11 What methods of assessing human performance capabilities will be most effective and useable during a Mars mission? (2) 6.12 What factors in systems and habitat design will best enhance the crew's ability to live and work in the space environment? How are these factors different from shorter duration missions? (2) 6.22 What theoretical, analytical and computational models of human performance best predict changes in human performance capabilities and characteristics in the context of a Mars mission, and enable designing and evaluating systems, procedures, and interface designs to mitigate negative changes in performance capabilities? (1)
Important References	Compton, W.D. Where no man has gone before: A history of Apollo Lunar Exploration Missions. NASA SP-4214, 1989
	Hancock, P.A., and Caird, J.K. Experimental evaluation of a model of mental workload. Human Factors, 35(3), 413-429, 1993
	Salvendy, G. Handbook of Human Factors, Second Edition. John Wiley & Sons, Inc., New York, New York, 1997
	Billings, C.E. Aviation automation: The search for a human-centered approach. Mahwah, NJ: Erlbaum, 1997
	Hollnagel, E. Reliability of cognition: Foundations of human reliability analysis. London: Academic Press, 1993
	Flight Crew Support Division Debriefs (Thagard, Lucid, Blaha, Linenger, Foale, Wolf

Risk Data Sheet

Risk number	21
Discipline Area	Human Behavior and Performance
Risk title	Human Performance Failure Because of Neurobehavioral Dysfunction
Contributing risk factors	Behavioral Health
Risk description	Human performance failure due to such conditions as depression, anxiety, trauma, or other neuropsychiatric dysfunction
Risk Rank	4
Risk Type (across risks)	III
Current risk mitigation status	4
Specific current cm(s) or mitigation(s)	1. Detection at the time of failure; 2. Rare opportunity for communication with crewmember
Specific projected cm(s) or mitigation(s)	1. Diagnostic method; 2. Computerized therapy; 3. Medication therapy; 4. Predictive model for risk of illness; 5. Individualized treatment algorithm developed preflight; 6. Holding environment for safety
Relationship to other risks and to other Discipline Areas	see Overall Human Performance Risk worksheet
Critical Questions (Priority):	6.13 What model(s) of behavioral health and task performance best predict problems and provide guidelines for effective treatment of illness (e.g., Depression, Anxiety, Trauma, Psychiatric Dysfunction)? (2) 6.15 What are the acute and long term effects of exposure to the space environment on the processes of sensation and perception, learning, cognition, decision-making, and motor skills and how do such changes affect human performance capabilities and behavior? (1) 6.14 What are the best countermeasures for rapidly recognizing and rapidly managing neurobehavioral dysfunction, emotional and stress-related dysfunction, neuropsychiatric dysfunction, and social psychological dysfunction, and how does the spaceflight environment affect their implementation? (2) 6.16 What are the acute and long term effects of exposure to other space environment (microgravity, isolation, stress) on the nervous system (at the cellular, molecular, or organismic levels) and on related neurobehavioral mechanisms, including neurobiology related to behavior and mood regulation? (2) 6.19 What are the acute and long term effects of exposure to the space environment on human emotion and psychological responses, including emotional reactivity, stress responses, long term modulation of mood, and vulnerability to affective disorders? (3) 6.20 What are the best methods of in-flight recognition, monitoring, and management of neurobehavioral dysfunction, including cognitive and perfornance dysfunction, emotional and stress-related dysfunction, neuropsychiatric dysfunction, and social psychological dysfunction? (1)
Important References	Gunderson, E.K.E. Mental Problems in Antarctica, Arch. of Environmental Health, 17: 558-564, 1968
	Matusov, Anatoly. Morbidity Among Members of the 10th Soviet Antarctic Expedition, Soviet Antarctic Expedition, 38-256, 1968
	Diagnostic and Statistical Manual of Mental Disorders, 1994 *need complete reference*
	Mintz, J., Mintz, L.I., Arruda, M.J., Hwang, S.S. Treatments of Depression and the Functional Capacity to Work, Archives of General Psychiatry, Vol. 49, October, 1992

7.0 Immunology, Infection and Hematology

Risk Data Sheet

Risk number	22
Discipline Area	Immunology, Infection and Hematology
Risk title	Immunodeficiency/Infections
Contributing risk factors	Stress; Radiation exposure; Decreased cell function; Altered environmental exposure
Risk description	Increased risk of infection due to: (1) impaired immune response (stress, radiation, decreased cell function); (2) altered environmental exposure; (3) persistent viruses or the reactivation of viruses
Risk Rank (within Discipline Area)	1
Risk Type (across risks)	II
Current risk mitigation status	4
Specific current cms	Pre-flight Quarantine (Health Stabilization Program)
Specific projected cms	Immunizations, immune system activators, viral suppression agents, environmental monitoring
Relationship to other risks and to other Discipline Areas)	Radiation Effects, Environmental Health, Food and Nutrition, Sleep and Circadian Rhythm Problems, Human Behavior and Performance
Critical Questions:	7.01 Are there assays of immune function that reliably predict immune compromise? (2)
	7.03 Do factors associated with flight (stress, environment, microgravity, nutritional status, radiation) affect humoral or cell-mediated immune function, mucosal immunity, non-specific immunity, or immune surveillance capabilities of crewmembers in a manner that exposes them to unacceptable medical risk (disease, allergy, delayed wound healing)? (1)
	7.10 Does the change in fluid distribution away from the extremities affect microcirculation in peripheral tissues, and does this represent a risk to the crew (wound healing, lymphocyte migration, immune surveillance)? (1)
	7.11 Does the spacecraft environment exert a selective pressure on environmental microorganisms which presents the crew with increased health risks (e.g. heliobacteria and ulcers)? (2)
	7.13 What diagnostic and environmental monitoring laboratory technologies need to be developed for the detection and diagnosis of infectious disease in microgravity? (3)
	7.17 Which potentially infectious agents will crewmembers be exposed to and what are their sources? (2)
	7.20 Does the loss of blood volume in spaceflight affect immune surveillance? (1)
	7.21 Does the altercation of sleep wake cycles produce alterations in chronobiology of immune responses due to upsetting the neuroendocrine axis and producing stress? (1)
	7.22 Are there countermeasures for spaceflight-associated defects in antibody, T-cell, phagocyte, and compliment systems? (1)
	7.23 Are there countermeasures for infections developed in space travel, especially latent virus infections? (1)
	7.25 Are there deficiencies of diet or micronutrients in long term space travel that would negatively impact on the CD4* T-Cell population and produce immonosupression? (2)
	7.26 Are there diet supplements or additives that could restore a malnutrition-induced state of immunosuppression? (2)
	7.28 Do conditions of mechanical forces of space travel disrupt cytokine: cytokine receptor signal transmissions in immune cells? (2)
	7.29 Are there surrogate marker essays that can be adapted to space travel that will quantitate the degree of immunodeficiency for antibody, T-cell, phagocyte, and implement function? (1)
	7. 04 Do factors associated with spaceflight increase reactivation of latent viruses? (2)
Important References	Tipton, CM, Greenlead, JE, Jackson, CG: Neuroendocrine and immune system responses with spaceflights. *Med Sci Sports Exerc* 28:988-98, 1996.
	J Leukocyte Bio 54:179-268, 1993.
	Sandberg, ET., Kline, MW., Shearer, WT. The Secondary Immunodeficiencies. In Stichm, ER., (Ed). Immunologic Disorders in Infants and Children. 4th Edition. Philadelphia: WB Saunders, pp. 553-602, 1996
	Noroski, LM, Shearer, WT. *Short Analytical Review: Screening for Primary Immunodeficiencies in the Clinical Laboratory. Clin Immunol Immunopath; 86: 237-245, 1998.*
	Grady, D. *Trapped at the South Pole, Doctor Becomes a Patient. New York Times, July 13: 1, 15, 1999.*

Risk Data Sheet

Risk number	23
Discipline Area	Immunology, Infection and Hematology
Risk title	Carcinogenesis Caused by Immune System Changes
Contributing risk factors	Radiation exposure; Chemical exposure; Viruses
Risk description	Increased risk due to: (1) increased oncogene expression (radiation induced or altered cell function); (2) decreased immune system surveillance; (3) reactivated viruses
Risk Rank (within Discipline Area)	1
Risk Type (across risks)	III
Current risk mitigation status	4
Specific current cms	Not specified
Specific projected cms)	Immune system activators, viral suppression agents
Relationship to other risks within Discipline Area and to other Discipline Areas	Dependent on countermeasures or mitigations of Radiation Effects Discipline Area
Critical Questions:	7.03 Do factors associated with flight (stress, environment, microgravity, nutritional status, radiation) affect humoral or cell-mediated immune function, mucosal immunity, non-specific immunity, or immune surveillance capabilities of crewmembers in a manner that exposes them to unacceptable medical risk (disease, allergy, delayed wound healing)? (1)
	7.01 Are there assays of immune function that reliably predict immune compromise? (2)
	7.04 Do factors associated with spaceflight increase reactivation of latent tumor viruses? (2)
	7.15 Which oncogenic mechanisms may be activated by in-flight radiation exposure? (2)
	7.18 What diagnostic and treatment capabilities are required for radiation induced illness? (3)
	7.14 What is the risk of cancer during or following long duration spaceflight? (1)
	7.29 Are there surrogate marker assays that can be adapted to space travel that will quantitate the degree of immunodeficiency for antibody, T-cell, phagocyte, and complement function? (1)
	7.24 Are there countermeasures for development of malignancy in space travel? (1)
	7.21 Does the altercation of sleep wake cycles produce alterations in chronobiology of immune responses due to upsetting the neuroendocrine axis and producing stress? (1)
	7.30 Does the change in fluid distribution affect microcirculation in peripheral tissues, and does this alter lymphocyte migration or immune surveillance)? (2)
Important References::	James JT: Carcinogens in spacecraft air. *Radiat Res* 148 (5 Suppl):11-16, 1997
	J Leukocyte Bio 54:179-268, 1993.

Risk Data Sheet

Risk number	24
Discipline Area	Immunology, Infection and Hematology
Risk title	Altered hemodynamic and cardiovascular dynamics caused by changes in blood components
Contributing risk factors	Loss of plasma and red blood cells due to exposure to microgravity
Risk description	Plasma volume decreases up to 25% during first 24 hours in space; there is a decrease of RBCM of 15% in the first week in space (2 units of blood); 15% loss of effective blood volume in the seven minutes preceding landing; aerobic capacity reduced due to decrease in RBCM; decrease in blood volume in bone and muscle may contribute to dysfunction of crew. This can be a severe risk to the mission for several hours and can have significant impact on the crew relating to rapid egress from the spacecraft.
Risk Priority (within Discipline Area)	1
Risk Type (across risks)	III
Current risk mitigation status	3
Specific current countermeasure(s) or mitigation(s)	Erythropoietin
Specific projected countermeasure(s) or mitigation(s)	In-flight monitoring of hematological parameters, Hematopoesis inducing agents, replacement of blood volume, use of artificial gravity to prevent volume losses
Relationship to other risks, Discipline Areas	
Critical Questions:	7.12 Does anemia following spaceflight diminish the aerobic capacity of individuals entering a gravitational environment or represent a risk to crewmembers on landing? (2)
	7.02 Can the physiologic mechanisms responsible for hematopoesis be influenced to increase red cell mass? (2)
	7.20 Does the loss of blood volume in spaceflight affect immune surveillance? (1)
	7.03 Do factors associated with flight (stress, environment, microgravity, nutritional status, radiation) affect humoral or cell-mediated immune function, non-specific immunity, mucosal immunity, or immune surveillance capabilities of crewmembers in a manner that exposes them to unacceptable medical risk (disease, allergy, delayed wound healing)? (1)
	7.29 Are there surrogate marker assays that can be adapted to space travel that will quantitate the degree of immunodeficiency for antibody, T-cell, phagocyte, and complement function? (1)
	7.31 Does the change in fluid distribution away from the extremities affect microcirculation in peripheral tissues, and does this represent a cardiovascular, muscle, or bone risk to the crew? (1)
Important References	Alfrey, CP, Udden, MM, Leach-Huntoon, C, Driscoll, T, Pickett, MH: Control of red blood cell mass in spaceflight. J Appl Physiol 81:98-104, 1996.
	Davis, TA, Wiesmann, W, Kidwell, W, Cannon, T, Kerns, L, Serke, C, Delaplaine, T, Pranger, A, Lee, KP: Effect of spaceflight on human stem cell hematopoiesis: suppression of erythropoiesis and myelopoiesis. J Leukoc Biol 60:69-76, 1996.
	Udden, MM, Driscoll, TB, Pickett, MH, Leach-Huntoon, CS, Alfrey, CP: Decreased production of red blood cells in human subjects exposed to microgravity. J Lab Clin Med 125:442-9, 1995.
	SLS1 and SLS2 Final Report
	Journal of Applied Physiology, 81: 90-104, 1996
	Journal of Applied Physiology, 81: 105-116, 1996
	Med. Sci. Sports Exercise, 28: 542-544, 1996
	Med. Sci. Sports Exercise, 28: 545-552, 1996.

Risk Data Sheet

Risk number	25
Discipline Area	Immunology, Infection and Hematology
Risk title	Altered wound healing
Contributing risk factors	Not specified
Risk description	Decreased immune response due to altered immune cell function or tissue localization/transport
Risk Rank (within Discipline Area)	2
Risk Type (across risks)	III
Current risk mitigation status	4
Specific current countermeasure(s) or mitigation(s)	Not specified
Specific projected countermeasure(s) or mitigation(s)	Antiseptic treatments, wound healing promoters
Relationship to other risks within Discipline Area and to other Discipline Areas	
Critical Questions:	7.03 Do factors associated with flight (stress, environment, microgravity, nutritional status, radiation) affect humoral or cell-mediated immune function, mucosal immunity, non-specific immunity, or immune surveillance capabilities of crewmembers in a manner that exposes them to unacceptable medical risk (disease, allergy, delayed wound healing)? (1)
	7.16 Which compounds can be used as effective promoters of wound healing? (3)
	7.01 Are there assays of immune function that reliably predict immune compromise? (2)
	7.29 Are there surrogate marker assays that can be adapted to space travel that will quantitate the degree of immunodeficiency for antibody, T-cell, phagocyte, and complement function? (1)
	7.32 Does the change in fluid distribution away from the extremities affect microcirculation in peripheral tissues, and does this represent a risk to the crew (wound healing, lymphocyte migration, immune surveillance)? (2)
Important References	*J Leukocyte Bio* 54:179-268, 1993.

Risk Data Sheet

Risk number	26
Discipline Area	Immunology, Infection and Hematology
Risk title	Altered host - microbial interactions
Contributing risk factors	Spacecraft environmental factors; Host defense factors; Nutrition
Risk description	Changes in microflora; alterations in host susceptibility; genetic change/mutation of microorganisms
Risk Rank (within Discipline Area)	3
Risk Type (across risks)	III
Current risk mitigation status	3
Specific current countermeasure(s) or mitigation(s)	In-flight environmental monitoring and bioburden reduction procedures.
Specific projected countermeasure(s) or mitigation(s)	In-flight antibiotic susceptibility testing capability; Preflight screening; In-flight microbial identification capability.
Relationship to other risks/Discipline Areas	Dependent on Environmental Microbiology monitoring and mitigations.
Critical Questions:	7.13 What diagnostic and environmental monitoring laboratory technologies need to be developed for the detection and diagnosis of infectious disease in space? (3)
	7.11 Does the spacecraft environment exert a selective pressure on environmental microorganisms which presents the crew with increased health risks (e.g., heliobacteria and ulcers)? (2)
	7.06 Does spaceflight alter microbial growth rates, mutation rates, or pathogenicity? (2)
	7.09 Does spaceflight alter the exchange of genetic material between microorganisms? (2)
	7.23 Are there countermeasures for infections developed in space travel, especially latent virus infections? (1)
	7.19 Does spaceflight alter host-microbe balance? (2)
Important References:	Not Specified

Risk Data Sheet

Risk number	27
Discipline Area	Immunology, Infection and Hematology
Risk title	Allergies and hypersensitivity reactions
Contributing risk factors	Exposure to environmental agents (chemical/biological); autoimmune disease
Risk description	Increased risk due to: (1) autoimmune disease from inappropriate response by immune system; (2) allergic hypersensitivity; (3) exposure to environmental (chemical/biological) agents
Risk Rank (within Discipline Area)	3
Risk Type (across risks)	II
Current risk mitigation status	3
Specific current countermeasure(s) or mitigation(s)	Toxicological/Environmental/Microbiological standards for spacecraft atmosphere.
Specific projected countermeasure(s) or mitigation(s)	Environmental control, immunizations/allergy therapy, immune system activators, viral suppression agents
Relationship to other risks within Discipline Area and to other Discipline Areas	Environmental Health
Critical Questions:	7.03 Do factors associated with flight (stress, environment, microgravity, nutritional status, radiation) affect humoral or cell-mediated immune function, mucosal immunity, non-specific immunity, or immune surveillance capabilities of crewmembers in a manner that exposes them to unacceptable medical risk (disease, allergy, delayed wound healing)? (1)
	7.01 Are there assays of immune function that reliably predict immune compromise? (2)
	7.29 Are there surrogate marker assays that can be adapted to space travel that will quantitate the degree of immunodeficiency for antibody, T-cell, phagocyte, and complement function? (1)
	7.23 Are there countermeasures for infections developed in space travel, especially latent virus infections? (1)
	7.05 Do unique environmental factors inside the spacecraft promote transmission of microbial pathogens, or cause increased risk of infection, allergy or hypersensitivity reactions independent of altered immune function? (2)
Important References:	Tipton, CM, Greenlead, JE, Jackson, CG: Neuroendocrine and immune system responses with spaceflights. *Med Sci Sports Exerc* 28:988-98, 1996.
	J Leukocyte Bio 54:179-268, 1993.

8.0 Muscle Alterations and Atrophy

Risk Data Sheet

Risk number	28
Discipline Area	Muscle Alterations and Atrophy
Risk title	Loss of skeletal muscle mass, strength and/or endurance
Contributing risk factors	Muscle atrophy; Decrease in muscle strength and muscle endurance; Altered motor performance; Altered muscle phenotype; Nutritional deficiencies (decreased carbohydrates); and Hormonal imbalance (circadian changes, dysregulation)
Risk description	The inability to perform emergency egress, landing and in partial gravity due to significant losses of muscle mass, strength and/or endurance. Such reduction would affect the ability to perform emergency egress, movements required for landing in partial gravity (fine motor control) and piloting prior to landing.
Risk Rank (within Discipline Area)	1
Risk Type (across risks)	II
Current risk mitigation status	4
Specific current countermeasure(s) or mitigation(s)	heavy resistive exercise, treadmill (continuous and interval running); cycle ergometry; rower ergometry
Specific projected countermeasure(s) or mitigation(s)	heavy resistive exercise, treadmill (continuous and interval running); cycle ergometry; rower ergometry (using higher technology equipment and more intense exercise and greater exercise duration in time and days); pharmacological/hormonal interventions
Relationship to other risks within Discipline Area and to other Discipline Areas	cardiovascular alterations, neurovestibular adaptation, bone loss, human performance, space medicine, immunology, infection and hematology, food and nutrition, environmental health, advanced life support
Critical Questions:	8.01 What are the appropriate prescription modalities and the compliance factors needed to minimize losses in muscle mass, strength and endurance, and facilitate rehabilitation? (1)
	8.02 To what extent should hormonal/pharmacological supplements be used as a countermeasure if exercise regimens are ineffective in maintaining homeostasis? (1)
	8.08 What are the appropriate exercise modalities and prescriptions needed to optimize skeletal muscle performance? (1)
	8.09 How do muscle cells sense the mechanical stress of gravity? (1)
	8.03 What is the role of, and what is necessary in order to establish the hormonal profile of astronauts during long duration spaceflight? (1)
Important References:	NASA, Space Life Sciences, Final Report Task Force on Countermeasures, (Chair, Kenneth M. Baldwin) May 1997

Risk Data Sheet

Risk number	29
Discipline Area	Muscle Alterations and Atrophy
Risk title	Inability to adequately perform tasks due to motor performance, muscle endurance and disruption in the structural and functional properties of the soft and hard connective tissues of the axial skeleton
Contributing risk factors	Muscle atrophy; Decrease in muscle strength and muscle endurance; Altered motor performance; Altered muscle phenotype; Nutritional deficiencies (decreased carbohydrates); and Hormonal imbalance (circadian changes, dysregulation)
Risk description	Inability to perform a variety of tasks associated with microgravity EVA, IVA and daily activities due to motor performance, muscle endurance and disruptions in the structural and functional properties (including phenotype) of the soft and hard connective tissues of the axial skeleton (i.e. intervertebral disk, lower back syndrome)
Risk Rank (within Discipline Area)	1
Risk Type (across risks)	II
Current risk mitigation status	4
Specific current countermeasure(s) or mitigation(s)	preflight regularly scheduled (6X week) crew physical training; heavy resistive exercise; treadmill (continuous and interval running); and cycle and rower ergometry
Specific projected countermeasure(s) or mitigation(s)	Individually tailored crew fitness training program preflight; heavy resistive exercise, treadmill (continuous and interval running); and cycle and rower ergometry (using higher technology equipment, more intense exercise, and greater exercise duration in time and days); pharmacological/hormonal interventions
Relationship to other risks within Discipline Area and to other Discipline Areas	Bone loss, cardiovascular alterations, neurovestibular adaptation, human performance, space medicine, immunology, infection and hematology, food and nutrition, environmental health, advanced life support
Critical Questions:	8.01 What are the appropriate prescription modalities and the compliance factors needed to minimize losses in muscle mass, strength and endurance? (1)
	8.02 To what extent should hormonal/pharmacological supplements be used as a countermeasure if exercise regimens are ineffective in maintaining homeostasis? (1)
	8.08 What are the appropriate exercise modalities and prescriptions needed to optimize skeletal muscle performance? (1)
	8.03 What is the role of, and what is necessary in order to establish the hormonal profile of astronauts during long duration spaceflight? (1)
Important References:	NASA, Space Life Sciences, Final Report Task Force on Countermeasures, (Chair, Kenneth M. Baldwin) May 1997

Risk Data Sheet

Risk number	30
Discipline Area	Muscle Alterations and Atrophy
Risk title	Inability to sustain muscle performance levels to meet demands of performing activities of varying intensities
Contributing risk factors	Muscle atrophy; Decrease in muscle strength and muscle endurance; Altered motor performance; Altered muscle phenotype; Nutritional deficiencies (decreased carbohydrates); and Hormonal imbalance (circadian changes, dysregulation)
Risk description	The inability to sustain muscle performance levels to meet the demands of performing mission-specific activities of varying intensities. Included in this risk are that deficits will exist in the maintenance of gait and posture that are required to complete these activities. An additional concern is that sufficient nutritional provisions may not be available to provide the necessary substrate energy to complete these tasks.
Risk Rank (within Discipline Area)	2
Risk Type (across risks)	II
Current risk mitigation status	5
Specific current countermeasure(s) or mitigation(s)	preflight fitness training and inflight exercise countermeasures
Specific projected countermeasure(s) or mitigation(s)	Ground-based exercise countermeasures on Martian surface for physiological improvements for surface tasks and return to Earth
Relationship to other risks within Discipline Area and to other Discipline Areas	Food and nutrition, neurovestibular adaptations, bone loss, cardiovascular alterations, neurovestibular adaptation, human performance, space medicine, immunology, infection and hematology, environmental health, advanced life support
Critical Questions:	8.04 What effect does long term spaceflight/operational countermeasures have on nitrogen balance (i.e., anabolic/catabolic control of protein expression)? (1)
	8.05 What are the effects of long term spaceflight on the metabolism of carbohydrates and fats, and what is their influence on sustained aerobic work and performance? (1)
Important References:	NASA, Space Life Sciences, Final Report Task Force on Countermeasures, (Chair, Kenneth M. Baldwin) May 1997

Risk Data Sheet

Risk number	31
Discipline Area	Muscle Alterations and Atrophy
Risk title	Propensity to develop muscle injury, connective tissue dysfunction, and bone fractures due to deficiencies in motor skill, muscle strength and muscular fatigue
Contributing risk factors	Muscle atrophy; Decrease in muscle strength and muscle endurance; Altered motor performance
Risk description	Propensity to develop muscle injury, connective tissue dysfunction, and bone fractures due to deficiencies in motor skill, muscle strength, and muscular fatigue.
Risk Rank (within Discipline Area)	3
Risk Type (across risks)	III
Current risk mitigation status	5
Specific current countermeasure(s) or mitigation(s)	preflight fitness training (6X week) and inflight exercise countermeasures; heavy resistive exercise; treadmill (continuous and interval running); and cycle and rower ergometry
Specific projected countermeasure(s) or mitigation(s)	Ground-based exercise countermeasures on Martian surface for physiological improvements for surface tasks and return to Earth ; Individually tailored crew fitness training program preflight; heavy resistive exercise, treadmill (continuous and interval running); and cycle and rower ergometry (using higher technology equipment, more intense exercise, and greater exercise duration in time and days); pharmacological/hormonal interventions
Relationship to other risks within Discipline Area and to other Discipline Areas	Food and nutrition, neurovestibular adaptations, bone loss, cardiovascular alterations, neurovestibular adaptation, human performance, space medicine, immunology, infection and hematology, environmental health, advanced life support
Critical Questions:	8.06 Do the deficits in skeletal muscle associated with long duration spaceflight affect the structural/functional properties of the sensory system and motor nerves? Describe the muscle tendon interface. (1)
	8.07 Do structural and functional deficits in the skeletal muscle system associated with long duration spaceflight impact: neurovestibular homeostasis; cardiovascular deconditioning; deficits in bone (regional and general); the muscle and tendon interface, and feedback from the skeletal muscle to the central nervous system (hypothalamus, hypophysis)? (1)
Important References:	NASA, Space Life Sciences, Final Report Task Force on Countermeasures, (Chair, Kenneth M. Baldwin) May 1997

Risk Data Sheet

Risk number	32
Discipline Area	Muscle Alterations and Atrophy
Risk title	Impact of deficits in skeletal muscle structure and function on other systems
Contributing risk factors	Muscle atrophy; Decrease in muscle strength and muscle endurance; Altered motor performance; Altered muscle phenotype; Nutritional deficiencies (decreased carbohydrates); and Hormonal imbalance (circadian changes, dysregulation)
Risk description	Deficits in skeletal muscle structure and function can impact the homeostasis of other systems including: neurovestibular/motor performance; vascular compliance and circulatory function impacting blood pressure regulation (e.g., skeletal muscle pump); soft and hard connective tissue integrity (e.g., tendon, bone, cartilage) and local versus general (e.g., tendon-bone interaction); radiation may alter the proliferation of muscle (satellite cell s) and bone forming cells (osteoblasts) which may alter the ability of these tissues to regenerate/repair; inadequate nutritional support may result in insufficient substrate energy and protein balance required for normal muscle performance.
Risk Rank (within Discipline Area)	Not rated (NR)*
Risk Type (across risks)	III
Current risk mitigation status	NR
Specific current countermeasure(s) or mitigation(s)	preflight fitness training (6X week) and inflight exercise countermeasures; heavy resistive exercise; treadmill (continuous and interval running); and cycle and rower ergometry
Specific projected countermeasure(s) or mitigation(s)	Ground-based exercise countermeasures on Martian surface for physiological improvements for surface tasks and return to Earth ; Individually tailored crew fitness training program preflight; heavy resistive exercise, treadmill (continuous and interval running); and cycle and rower ergometry (using higher technology equipment, more intense exercise, and greater exercise duration in time and days); pharmacological/hormonal interventions
Relationship to other risks within Discipline Area and to other Discipline Areas	Cardiovascular alterations, radiation effects, food and nutrition, bone loss, neurovestibular adaptation
Critical Questions:	8.06 Do the deficits in skeletal muscle associated with long duration spaceflight affect the structural/functional properties of the sensory and motor nerves? Describe the muscle tendon interface. (1)
	8.07 Do structural and functional deficits in the skeletal muscle system associated with long duration spaceflight impact: neurovestibular homeostasis; cardiovascular deconditioning; deficits in bone (regional and general); the muscle and tendon interface, and feedback from the skeletal muscle to the central nervous system (hypothalamus, hypophysis)? (1)
Important References:	NASA, Space Life Sciences, Final Report Task Force on Countermeasures, (Chair, Kenneth M. Baldwin) May 1997

*NR: not currently rated by Discipline Area team

9.0 Neurovestibular Adaptation

Risk Data Sheet

Risk number	33
Discipline Area	Neurovestibular Adaptation
Risk title	Disorientation and Inability to Perform Landing, Egress, or Other Physical Tasks, Especially During/After G-level Changes (Acute spontaneous & provoked vertigo, nystagmus, oscillopsia, poor dynamic visual acuity)
Contributing risk factors	Sleep disorders; Sleep disruption; Circadian dysrhythmia; Impaired cognitive or psychomotor performance; Space motion sickness
Risk description	Spatial disorientation, sensory illusions and motor performance problems involving locomotion and posture often accompany exposure to a new and different gravitational field. These adaptations are usually transient in nature but can adversely impact cognitive performance and motor skills during emergency egress procedures, or may result in the inability to complete a Mars landing phase manual re-entry. Any significant duration or magnitude of gravitoinertial forces will affect any other critical performance. Countermeasure would be totally automated landing system.
Risk Rank (within Discipline Area)	1
Risk Type (across risks)	II
Current risk mitigation status	2
Specific current countermeasure(s) or mitigation(s)	Exercise regimes
Specific projected countermeasure(s) or mitigation(s)	Resistive exercise, Martian surface with 1/3 G
Relationship to other risks and to other Discipline Areas	Human Behavior and Performance
Critical Questions (priority):	9.01 What are the pros and cons of artificial gravity (AG) as a countermeasure? What are the advantages and disadvantages of large radius continuous AG vs. short radius, intermittent AG? (1)
	9.02 What are the appropriate ground-based spaceflight analog environments that can be used as test beds for evaluating neurological adaptation time constants, adverse operational implications, countermeasures, and impacts of adaptation on other anatomical and physiological systems? (2)
	9.03 How do altered time constants associated with neurological (sensorimotor, autonomic, emetic) adaptation to spaceflight (microgravity and 1/3 Mars surface) correlate with physiological and operational performance changes? (3)
	9.04 How do countermeasures (e.g., artificial gravity, inflight exercise, or preflight training) affect adaptation time constraints? (3)
	9.05 How do the large inter-individual differences in response to altered magnitude and duration of gravito-inertial forces (weightlessness and return to Earth) correlate with physiological and operational performance changes? (3)
	9.08 How do visual, vestibular and haptic cues contribute to inversion illusions, visual reorientation, illusions, EVA acrophobia, disorientation and poor 3D spatial memory problems in 0-G? (2)
	9.09 What is the physiological basis of inversion illusions, visual reorientation, and 3D memory problems in 0-G? (2)
	9.10 Can preflight training techniques (e.g. virtual reality simulations) be used to alleviate these problems, and to evaluate emergency procedures? (2)
	9.25 What is the physiological basis for oscillopsia, disorientation, and reduced dynamic visual acuity reported by crewmembers making head movements during re-entry? (2)
	9.27 How can 0-G immersive teleoperation displays be designed to reduce disorientation and/or motion sickness? (2)
Key References	Not Specified

Risk Data Sheet

Risk number	34
Discipline Area	Neurovestibular Adaptation
Risk title	Impaired Neuromuscular Coordination and/or Strength (Gait ataxia, postural instability)
Contributing risk factors	Acute or intermittent exposure to 0-G, Re-exposure to 1-G or reentry/landing accelerations, Head movements about any axis, Walking or running after landing, Ambiguous or misleading visual cues for spatial orientation; Coriolis effects in rotating environments, Vomiting; exacerbated by post flight orthostatic hypotension and/or muscular deconditioning.
Risk description	Impaired neuromuscular strength upon return to positive G leading to increased occurrence of falls and fractures during emergency egress and escape
Risk Rank (within Discipline Area)	2
Risk Type (across risks)	II
Current risk mitigation status	3
Specific current countermeasure(s) or mitigation(s)	Resistive exercise regimes
Specific projected countermeasure(s) or mitigation(s)	Artificial gravity
Relationship to other risks within Discipline Area and to other Discipline Areas	Human Behavior and Performance
Critical Questions (priority):	9.01 What are the tradeoffs of artificial gravity as a countermeasure for neurovestibular deficits? What are the risks/benefits of long-arm continuous versus short-arm, within-craft, intermittent artificial gravity countermeasures? (1)
	9.02 What are the appropriate ground-based spaceflight analog environments that can be used as test beds for evaluating neurological adaptation time constraints, adverse operational implications, countermeasures, and impacts of adaptation on other anatomical and physiological systems? (2)
	9.04 How do countermeasures (e.g., artificial gravity, inflight exercise, or preflight training) affect adaptation time constraints? (3)
	9.05 How do the large inter-individual differences in response to altered magnitude and duration of gravito-inertial forces (weightlessness and return to Earth) correlate with physiological and operational performance changes? (3)
	9.22 What is the relative contribution of neurovestibular adaptation, neuromuscular deconditioning, and orthostatic intolerance to postflight neuromuscular coordination, ataxia, and locomotion difficulties? (3)
	9.24 Can preflight or inflight training, or sensory aids and protheses, improve postlanding postural and locomotor control? (2)
Key References:	Not Specified

Risk Data Sheet

Risk number	35
Discipline Area	Neurovestibular Adaptation
Risk title	Impaired Cognitive and/or Physical Performance Due to Motion Sickness Symptoms or Treatments, Especially During/After G-level Changes (Including short term memory loss, reaction time increase, drowsiness, fatigue, torpor, irritability, ketosis)
Contributing risk factors	Change in gravity levels
Risk description	Any change in gravitoinertial forces can result in SMS (nausea, disorientation, dizziness, vomiting, and loss of appetite, drowsiness) and could degrade performance. Only countermeasure/risk mitigations currently available are drugs that are showing to have undesirable side effects. Continued concern is based on Russian observation that 94% of returning long duration crews still experience motion sickness after standing.
Risk Rank (within Discipline Area)	3
Risk Type (across risks)	III
Current risk mitigation status	3
Specific current countermeasure(s) or mitigation(s)	Promethazine; Controlled head movements during take-off and landing; Pre-adaptation training (PAT) in simulated environments; Restricted head movements
Specific projected countermeasure(s) or mitigation(s)	Antimotion Sickness Medication; Artificial G
Relationship to other risks within Discipline Area and to other Discipline Areas	Clinical Capabilities, Human Behavior and Performance
Critical Questions (priority):	9.11 What physical and cognitive performance will be required of the crew during the acceleration/deceleration portions of the mission? (2)
	9.12 How effective is promethazine injection (or other drugs) in providing fast relief in mission critical situations? Does the drug have unacceptable side effects, particularly the short-term effects on cognitive function? (1)
	9.23 To what extent can neurovestibular adaptation to weightlessness and/or artificial gravity take place in context specific fashion, so crewmembers can be adapted to multiple environments and switch between them without suffering disorientation or motion sickness? (2)
	9.26 What is the physiological basis of space motion sickness? How does chronic space motion sickness (including sopite syndrome) affect mood, initiative, and interpersonal relationships? (2)
	9.27 How can 0-G immersive teleoperation displays be designed to reduce disorientation and/or motion sickness? (2)
Important References:	Not Specified

Risk Data Sheet

Risk number	36
Discipline Area	Neurovestibular Adaptation
Risk title	Vestibular Contribution to Cardioregulatory Dysfunction (Postlanding orthostatic intolerance, sleep and mood changes)
Contributing risk factors	Return to 1 G
Risk description	On return to positive gravity environment, vestibular interaction with autonomic system leads to syncope
Risk Priority (within Discipline Area)	4
Risk Type (across risks)	III
Current risk mitigation status	4
Specific current countermeasure(s) or mitigation(s)	Pre-adaptation training, exercise
Specific projected countermeasure(s) or mitigation(s)	Fully autonomic landing system; Inflight Landing Control Practice; Preflight egress training, Crew station design; Resistive exercise
Relationship to other risks and to other Discipline Areas	Cardiovascular Alterations; Muscle Alterations and Atrophy
Critical Questions:	9.15 Does neurovestibular adaptation to weightlessness impair postlanding cardiovascular regulation and contribute to orthostatic intolerance? (1)
	9.16 Do vestibular countermeasures improve postlanding cardiovascular regulation and orthostatic tolerance? (1)
	9.17 How does neurovestibular adaptation contribute to postlanding postural control and locomotion difficulties? (2)
	9.22 What is the relative contribution of neurovestibular adaptation, neuromuscular deconditioning, and orthostatic intolerance to postflight neuromuscular coordination, ataxia and locomotion difficulties? (2)
	9.23 To what extent can neurovestibular adaptation to weightlessness and/or artificial gravity take place in context specific fashion, so crewmembers can be adapted to multiple environments and switch between them without suffering disorientation or motion sickness? (2)
Important References:	Not specified

Risk Data Sheet

Risk number	37
Discipline Area	Neurovestibular Adaptation
Risk title	Possible Chronic Impairment of Orientation or Balance Function Due to Microgravity or Radiation (Imbalance, gait ataxia, vertigo, chronic vestibular insufficiency, poor dynamic visual acuity)
Contributing risk factors	Radiation exposure; Prolonged exposure to microgravity
Risk description	Prolonged exposure (or successful adaptation) to an altered gravitational environment may result in irreversible changes in neurological structure and function and can lead to performance decline, poor morale and shift to early return scenario.
Risk Rank (within Discipline Area)	5
Risk Type (across risks)	III
Current risk mitigation status	5
Specific current countermeasure(s) or mitigation(s)	None
Specific projected countermeasure(s) or mitigation(s)	Not specified
Relationship to other risks within Discipline Area and to other Discipline Areas	Muscle Alterations and Atrophy, Clinical Capabilities, Human Behavior and Performance
Critical Questions:	9.20 What are the significant irreversible changes in sensory-motor neurological function associated physiological systems, and anatomical and/or biochemical processes that may be caused by exposure or development in long duration 0-G or partial –G and what are the mechanisms and time course? (4)
	9.21 How can these changes be optimally distinguished from the normal responses to stress, isolation, and normal background physiological variability? What countermeasures can be developed? (4)
	9.24 Can preflight training or inflight training, or sensory aids and protheses, improve postlanding and locomotor control? (2)
Important References:	Not Specified

10.0 Radiation Effects

Risk Data Sheet

Risk number	38
Discipline Area	Radiation Effects
Risk title	Carcinogenesis Caused by Radiation
Contributing risk factors	Genetic susceptibility; Nutrition; Immune function; Growth factors; Stress; Environmental mutagens; Age; Gender
Risk description	Ionizing radiation can effectively induce various types of tumors in humans as both an initiator and promotor. Except leukemia, which has relatively short latency period, solid tumors usually take more than ten years to develop after irradiation.
Risk Rank (within Discipline Area)	1
Risk Type (across risks)	I
Current risk mitigation status	4
Specific current countermeasure(s) or mitigation(s)	bone marrow transplantation, nutrition, antibiotics, growth factors, spacecraft shielding, body shielding, active dose rate monitors, passive crew dosimeters, biodosimetry, dose management, ground solar particle event warning system
Specific projected countermeasure(s) or mitigation(s)	genetic screening for individual sensitivity, chemical radioprotectants with minimum side effects, cancer progression inhibitors, biological markers for space radiation damage in cells, biophysical computer models for accurate health risk assessment, active neutron spectrometer, active soft x-ray detector for solar particle events, new shielding materials and methods
Relationship to other risks within Discipline Area and to other Discipline Areas	Immunology, Infections and Hematology
Critical Questions:	10.09 What are the cancer risks in humans from spaceflight? (1)
	10.11 What is the acceptable accuracy for risks of acute and late effects in humans from photons to adequately extrapolate to space? (1)
	10.05 Are there unique biological effects associated with HZE's? (1)
	10.06 Do we have strategies for calculating risks that are adequate if expected data are provided and what are uncertainties? (2)
	10.07 How can animal and cell experiments be done and data best be used to extrapolate to the human risk from space radiation? (1)
	10.01 Are the biological effects for protons above 10 MeV sufficiently similar to photons that photon data can be used for their consequences? (3)
	10.10 What are the risks from SPE's and what is their impact on operations, EVAs and surface exploration? (1)
	10.04 Are there differences in response to particles with similar LET, but with different atomic numbers and energies? (2)
	10.12 What are the effects of age, gender, and inter-individual diversity? (2)
	10.08 How do the thickness, design, and material composition of space vehicles affect the internal radiation environment and biological assessment? (1)
	10.03 Are there chemopreventive or biological agents which would mitigate acute or late effects? (3)
Important References:	NCRP Report No. 98 “Guidance on Radiation Received in Space Activities” (1989)
	NRC Report “Radiation Hazards to Crews of Interplanetary Missions: Biological Issues and Research Strategies” (1997)
	International Commission on Radiological Protection (ICRP) Report 60 “Recommendations of the International Commission on Radiological Protection” (1990)
	Robbins, D. E. and T. C. Yang (1994) Chapter 9. Radiation and Radiobiology. In: Space Physiology and Medicine. Ed. A. E. Nicogossian, C. L. Huntoon, and S. L. Pool. Lea & Febiger, Philadelphia, PA

Risk Data Sheet

Risk number	39
Discipline Area	Radiation Effects
Risk title	Late Degenerative Tissue Effects including Non-Cancer Mortality, Cataracts, and Central Nervous System (CNS) Effects
Contributing risk factors	Genetic susceptibility; Extracellular milieu; Environmental toxic agents
Risk description	Ionizing radiation can damage cells in central nervous system, such as glial cells and neurons. The effectiveness of space radiation, particularly heavy charged particles with high linear energy transfer, in damaging central nervous system is not well known, but is expected to be very high.
Risk Rank (within Discipline Area)	2
Risk Type (across risks)	II
Current risk mitigation status	5
Specific current countermeasure(s) or mitigation(s)	bone marrow transplantation, nutrition, antibiotics, growth factors, spacecraft shielding, body shielding, active dose rate monitors, passive crew dosimeters, biodosimetry, dose management, ground solar particle event warning system
Specific projected countermeasure(s) or mitigation(s)	genetic screening for individual sensitivity, chemical radioprotectants with minimum side effects, cancer progression inhibitors, biological markers for space radiation damage in cells, biophysical computer models for accurate health risk assessment, active neutron spectrometer, active soft x-ray detector for solar particle events, new shielding materials and methods
Relationship to other risks within Discipline Area and to other Discipline Areas	
Critical Questions:	10.11 What is the acceptable accuracy for risks of acute and late effects in humans from photons to adequately extrapolate to space? (2)
	10.05 Are there unique biological effects associated with HZE's? (1)
	10.06 Do we have strategies for calculating risks that are adequate if expected data are provided and what are uncertainties? (3)
	10.07 How can animal and cell experiments be done and data best be used to extrapolate to the human risk from space radiation? (1)
	10.01 Are the biological effects for protons above 10 MeV sufficiently similar to photons that photon data can be used for their consequences? (3)
	10.10 What are the risks from SPE's and what is their impact on operations, EVAs and surface exploration? (1)
	10.04 Are there differences in response to particles with similar LET, but with different atomic numbers and energies? (2)
	10.12 What are the effects of age, gender, and inter-individual diversity? (2)
	10.08 How do the thickness, design, and material composition of space vehicles affect the internal radiation environment and biological assessment? (1)
	10.03 Are there chemopreventive or biological agents which would mitigate acute or late effects? (3)
Important References:	NCRP Report No. 98 “Guidance on Radiation Received in Space Activities” (1989)
	NRC Report “Radiation Hazards to Crews of Interplanetary Missions: Biological Issues and Research Strategies” (1997)
	International Commission on Radiological Protection (ICRP) Report 60 “Recommendations of the International Commission on Radiological Protection” (1990)
	Robbins, D. E. and T. C. Yang (1994) Chapter 9. Radiation and Radiobiology. In: Space Physiology and Medicine. Ed. A. E. Nicogossian, C. L. Huntoon, and S. L. Pool. Lea & Febiger, Philadelphia, PA

Risk Data Sheet

Risk number	40
Discipline Area	Radiation Effects
Risk title	Synergistic effects from exposure to radiation, microgravity, and other spacecraft environmental factors
Contributing risk factors	Microgravity or weightlessness; Genetic susceptibility; Environmental cytotoxic and mutagenic compounds
Risk description	Cellular responses to ionizing radiation can be modified directly or indirectly by other environmental factors, such as weightlessness and cytotoxic compounds present in the spacecraft. The total biological effects of radiation and another environmental factor can be more than additive.
Risk Rank (within Discipline Area)	3
Risk Type (across risks)	II
Current risk mitigation status	5
Specific current countermeasure(s) or mitigation(s)	bone marrow transplantation, nutrition, antibiotics, growth factors, spacecraft shielding, body shielding, active dose rate monitors, passive crew dosimeters, biodosimetry, dose management, ground solar particle event warning system
Specific projected countermeasure(s) or mitigation(s)	genetic screening for individual sensitivity, chemical radioprotectants with minimum side effects, cancer progression inhibitors, biological markers for space radiation damage in cells, biophysical computer models for accurate health risk assessment, active neutron spectrometer, active soft x-ray detector for solar particle events, new shielding materials and methods
Relationship to other risks and to other Discipline Areas	Immunology, Infections and Hematology; Environmental Health
Critical Questions:	10.09 What are the cancer risks in humans from spaceflight? (1)
	10.05 Are there unique biological effects associated with HZE's? (2)
	10.06 Do we have strategies for calculating risks that are adequate if expected data are provided and what are uncertainties? (2)
	10.02 Are there adverse synergism's between radiation and other space environmental and biological factors? (1)
	10.03 Are there chemopreventive or biological agents which would mitigate acute or late effects? (3)
	10.07 How can animal and cell experiments be done and data best be used to extrapolate to the human risk from space radiation? (1)
	10.12 What are the effects of age, gender, and inter-individual diversity? (2)
Important References:	NCRP Report No. 98 "Guidance on Radiation Received in Space Activities" (1989)
	NRC Report "Radiation Hazards to Crews of Interplanetary Missions: Biological Issues and Research Strategies" (1997)
	International Commission on Radiological Protection (ICRP) Report 60 "Recommendations of the International Commission on Radiological Protection" (1990)
	Robbins, D. E. and T. C. Yang (1994) Chapter 9. Radiation and Radiobiology. In: Space Physiology and Medicine. Ed. A. E. Nicogossian, C. L. Huntoon, and S. L. Pool. Lea & Febiger, Philadelphia, PA

Risk Data Sheet

Risk number	41
Discipline Area	Radiation Effects
Risk title	Early or acute effects from radiation exposure
Contributing risk factors	Genetic susceptibility; Stress; Immune function; Environmental toxic agents
Risk description	Ionizing radiation can cause damages in nervous system, intestinal tract, and blood forming organs. The manifestation of the damages in these tissues can be short; within days, weeks and months, depending on radiation dose.
Risk Rank (within Discipline Area)	4
Risk Type (across risks)	II
Current risk mitigation status	3
Specific current countermeasure(s) or mitigation(s)	bone marrow transplantation, nutrition, antibiotics, growth factors, spacecraft shielding, body shielding, active dose rate monitors, passive crew dosimeters, biodosimetry, dose management, ground solar particle event warning system
Specific projected countermeasure(s) or mitigation(s)	genetic screening for individual sensitivity, chemical radioprotectants with minimum side effects, cancer progression inhibitors, biological markers for space radiation damage in cells, biophysical computer models for accurate health risk assessment, active neutron spectrometer, active soft x-ray detector for solar particle events, new shielding materials and methods
Relationship to other risks within Discipline Area and to other Discipline Areas	Environmental Health
Critical Questions:	10.11 What is the acceptable accuracy for risks of acute and late effects in humans from photons to adequately extrapolate to space? (1)
	10.05 Are there unique biological effects associated with HZE's? (2)
	10.06 Do we have strategies for calculating risks that are adequate if expected data are provided and what are uncertainties? (2)
	10.07 How can animal and cell experiments be done and data best be used to extrapolate to the human risk from space radiation? (1)
	10.01 Are the biological effects for protons above 10 MeV sufficiently similar to photons that photon data can be used for their consequences? (3)
	10.10 What are the risks from SPE's and what is their impact on operations, EVAs and surface exploration? (1)
	10.12 What are the effects of age, gender, and inter-individual diversity? (2)
	10.04 Are there differences in response to particles with similar LET, but with different atomic numbers and energies? (2)
	10.08 How do the thickness, design, and material composition of space vehicles affect the internal radiation environment and biological assessment? (1)
	10.03 Are there chemopreventive or biological agents which would mitigate acute or late effects? (3)
Important References:	NCRP Report No. 98 “Guidance on Radiation Received in Space Activities” (1989)
	NRC Report “Radiation Hazards to Crews of Interplanetary Missions: Biological Issues and Research Strategies” (1997)
	International Commission on Radiological Protection (ICRP) Report 60 “Recommendations of the International Commission on Radiological Protection” (1990)
	Robbins, D. E. and T. C. Yang (1994) Chapter 9. Radiation and Radiobiology. In: Space Physiology and Medicine. Ed. A. E. Nicogossian, C. L. Huntoon, and S. L. Pool. Lea & Febiger, Philadelphia, PA

Risk Data Sheet

Risk number	42
Discipline Area	Radiation Effects
Risk title	Radiation Effects on Fertility, Sterility, and Heredity
Contributing risk factors	Genetic susceptibility; Age; Gender; Environmental toxic agents
Risk description	Human reproductive organs can be sensitive to ionizing radiation. The seminiferous epithelium is among the most radiosensitive tissues in male adults. Human data suggest that long periods of exposure to low dose rates of ionizing radiation can cause sterility and infertility. Also experimental data showed that ionizing radiation can cause genetic alterations in germ cells. The effectiveness of charged particles in inducing fertility, sterility and heredity effects has not been studied in detail.
Risk Rank (within Discipline Area)	5
Risk Type (across risks)	III
Current risk mitigation status	2
Specific current countermeasure(s) or mitigation(s)	bone marrow transplantation, nutrition, antibiotics, growth factors, spacecraft shielding, body shielding, active dose rate monitors, passive crew dosimeters, biodosimetry, dose management, ground solar particle event warning system
Specific projected countermeasure(s) or mitigation(s)	genetic screening for individual sensitivity, chemical radioprotectants with minimum side effects, cancer progression inhibitors, biological markers for space radiation damage in cells, biophysical computer models for accurate health risk assessment, active neutron spectrometer, active soft x-ray detector for solar particle events, new shielding materials and methods
Relationship to other risks within Discipline Area and to other Discipline Areas	Environmental Health
Critical Questions:	10.12 What are the effects of age, gender, and inter-individual diversity? (3)
	10.13 What are the risks associated with fertility, sterility, and hereditary effects as a result of exposure to radiation on long duration missions? (3)
Important References:	NCRP Report No. 98 "Guidance on Radiation Received in Space Activities" (1989)
	NRC Report "Radiation Hazards to Crews of Interplanetary Missions: Biological Issues and Research Strategies" (1997)
	International Commission on Radiological Protection (ICRP) Report 60 "Recommendations of the International Commission on Radiological Protection" (1990)
	Robbins, D. E. and T. C. Yang (1994) Chapter 9. Radiation and Radiobiology. In: Space Physiology and Medicine. Ed. A. E. Nicogossian, C. L. Huntoon, and S. L. Pool. Lea & Febiger, Philadelphia, PA

11.0 Clinical Capabilities

Risk Data Sheet

Risk number	43	
Discipline Area	Clinical Capabilities	
Risk title	Trauma and Acute Medical Problems	
Contributing Risk factors	Prolonged exposure to microgravity and transitions to altered gravity levels upon landing on planetary surfaces; isolated and confined environment; highly autonomous operations with delayed communications	
Risk description	The inability to diagnose and treat illness in microgravity	
Risk Rank Order (within Discipline Area)	1	
Risk Type (across risks)	I	
Current risk mitigation status	3	
Specific current countermeasure(s) or mitigation(s)	Oral isotonic solution, anti-g trousers, thermal control, body orientation and head movement protocols for re-entry, postflight adaptation protocols, inflight aerobic exercise, medications (promethazine for SMS), selection criteria, training, radiation risk management procedures, balanced diet	
Specific projected countermeasure(s) or mitigation(s)	Acute and chronic diagnostic and monitoring capabilities; smart medical systems ; advanced medical imaging and telemedicine capabilities; optimal protocols for on-orbit management of injuries	
Relationship to other risks within Discipline Area and to other Discipline Areas	Bone Loss, CV Alterations, Environmental Health, Food and Nutrition, Human Behavior and Performance, Immunology, Muscle Alterations and Atrophy, NV Adaptation, Radiation Effects	
Critical Questions:	11.01	What are the essential technologies, resources, procedures, skills and training necessary to provide effective advanced life support (CPR, ACLS, ATLS) in space? (1)
	11.02	What acute and chronic diagnostic and monitoring capabilities (hardware, software, communication and data management capabilities, "smart" systems, and training) is necessary to support acute trauma, surgical and medical intervention in space? (1)
	11.03	What medical imaging and telemedicine (including medical informatics) capabilities (technology, skills and training) are necessary to support space medicine? (1)
	11.04	What are the specific techniques, resources, protocols, skills and equipment (technology) necessary to perform surgical intervention and care in the space environment (including options and techniques for anesthesia)? (2)
	11.05	What are effective methods and technologies for fluid (IV and other) resuscitation and transfusion in space (including blood replacement products)? (2)
	11.06	What are the optimal treatment methods, technologies, and protocols for the on-orbit management of acute musculoskeletal injuries (including sprains, strains, contusions and fractures)? (2)
	11.07	What are the most effective options, protocols, and technologies to support patient transport and return to Earth definitive medical care facility? (2)
	11.08	What are the optimal technologies for supporting an autonomous acute medical response capability in space, including medical informatics, smart medical care systems, on orbit skills maintenance and training? (1)
	11.09	What are the procedures and protocols for pronouncement of death in space and for the management of a cadaver? (3)
	11.10	What are the essential technologies, resources, skills, and training necessary to effectively diagnose, treat, and recover patients from likely acute medical emergencies in space including, but not limited to the following: (1) - Wounds, lacerations, and burns - Toxic exposure and acute anaphylaxis (including drug reactions) - Acute radiation illness - Dental emergencies - Ophthalmologic emergencies - Gynecologic and urology emergencies - Psychiatric emergencies
	11.11	What are the technologies, methods, resources, and skills necessary to accomplish chronic care and recovery following an acute medical or surgical event in space? (1)
	11.12	What technologies are feasible and should be developed to support non-invasive or minimally invasive medical diagnosis and intervention capabilities in space? (1)
Important References:	Medical Policy Board: Medical Procedures and Requirements Document, Third Revision, NASA Headquarters	
	Nicogossian, A.E., Huntoon, C.L., and Pool, S.L., Space Physiology and Medicine, Third Edition, Lea and Febiger, PA., 1994	

Risk Data Sheet

Risk number	44
Discipline Area	Clinical Capabilities
Risk title	Toxic Exposure
Contributing Risk factors	Enclosed spacecraft, chemical leak, increased or altered sensitivity of individuals to environmental agents, allergies, stress, changes in immune system response, inadequate ALS, prolonged dwelling in an enclosed environment
Risk description	Unexpected toxic contamination of spacecraft living environment from chemicals, microbes, or other contaminants inside the living quarters of the space vehicle; or increased sensitivity of individuals to environmental sources of contamination
Risk Rank (within Discipline Area)	2
Risk Type)	II
Current risk mitigation status	3
Specific current countermeasure(s) or mitigation(s)	Sensors, monitoring and control systems for air and water (microbial, chemicals and other contaminants, decontamination protocols
Specific projected countermeasure(s) or mitigation(s)	Advanced sensors, screening, pharmacological treatments, crew screening and selection criteria, adequate nutrition/diet, stress reduction protocols, shielding, protective garments and devices
Relationship to other risks within Discipline Area and to other Discipline Areas	Human Behavior and Performance; Cardiovascular Alterations; Neurovestibular Adaptation; Immunology, Infection and Hematology; ALS; Environmental Health; Radiation Effects
Critical Questions:	11.13 What diagnostic, monitoring and treatment capabilities are essential for management of toxic exposure (acute and chronic)? (1)
	11.14 What crew screening and selection criteria should be developed and implemented to identify individuals who are at increased risk for developing hypersensitivity or allergies to spaceflight compounds, exposures, or payloads? (2)
	11.15 What countermeasures should be developed and implemented to prevent adverse reactions to toxic exposures (e.g. sleep, nutritional, medications, stress reduction, shielding, protective equipment, etc.)? (2)
Important References:	Medical Policy Board: Medical Procedures and Requirements Document, Third Revision, NASA Headquarters
	Nicogossian, A.E., Huntoon, C.L., and Pool, S.L., Space Physiology and Medicine, Third Edition, Lea and Febiger, PA., 1994

Risk Data Sheet

Risk number	45
Discipline Area	Clinical Capabilities
Risk title	Altered Pharmacodynamics and Adverse Drug Reactions
Contributing risk factors	Polypharmacy (multidrug administration), idiosyncratic tendencies, allergies, pharmocotherapeutic changes in microgravity (e.g., adsorption changes metabolism; drug effect changes-SMS)
Risk description	Drug interactions, adverse reactions to medications given as countermeasures for bone loss, adverse reaction of bone to drugs given for other reasons.
Risk Rank (within Discipline Area)	3
Risk Type	III
Current risk mitigation status	2
Specific current countermeasure(s) or mitigation(s)	none
Specific projected countermeasure(s) or mitigation(s)	Advanced diagnostics and laboratory technologies to predict and manage medication side effects, toxicity and interactions during spaceflight
Relationship to other risks within Discipline Area and to other Discipline Areas	Bone loss, Food and nutrition; Cardiovascular Alterations; Neurovestibular Adaptation; Human Behavior and Performance; Muscle Alterations and Atrophy (coordination of team efforts to minimize medication use and explore alternatives)
Critical Questions:	11.16 What are the effects and implications of spaceflight alterations in human physiology on the absorption, distribution, metabolism, clearance, excretion, clinical efficacy, side effects and drug interactions for clinically useful medications? (2)
	11.17 What technologies are available to provide extended shelf-life pharmaceuticals for long duration spaceflight? (1)
	11.18 What are the side effect and interaction profiles of the commonly use medications in spaceflight, and how should the crew and medical team be trained and prepared to recognize and deal with these issues? (2)
	11.19 What are the most appropriate dosages and routes of administration for the spaceflight clinically useful medications (taking into consideration the answers to question number 11.16)? (1)
	11.20 What diagnostic and laboratory technologies are necessary to predict and manage medication side effects, interactions, and toxicity during spaceflight? (1)
	11.21 What is the effectiveness, indications and risks, and proper utilization of popular non-traditional herbal and nutritional supplements and other alternative therapies (such as homeopathy, etc.)? (3)
Important References	Not specified

Risk Data Sheet

Risk number	46
Discipline Area	Clinical Capabilities
Risk title	Illness and Ambulatory Problems
Contributing Risk factors	Prolonged exposure to microgravity and transitions to altered gravity levels upon landing on planetary surfaces; isolated and confined environment; highly autonomous operations with delayed communications
Risk description	
Risk Rank (within Discipline Area)	4
Risk Type (across risks)	III
Current risk mitigation status	2
Specific current countermeasure(s) or mitigation(s)	Preflight fitness and quarantine protocols; clinical norms based on epidemiological study
Specific projected countermeasure(s) or mitigation(s)	Risk assessment and acceptability for incidence of illness and injury associated with spaceflight; Improved crew training procedures and systems; telemedicine and medical imaging systems, smart medical systems; improved habitability monitoring systems (microbial, toxicological, radiation, noise and lighting levels); alternative medicine approaches
Relationship to other risks within Discipline Area and to other Discipline Areas	Human Performance; Cardiovascular Alterations; Neurovestibular Adaptation; Muscle Alterations and Atrophy; Food and Nutrition
Critical Questions:	11.22 What are the methods, technologies, and standards for conducting a nominal health and fitness examination in space (including interval history and physical, baseline diagnostics, and data management)? (1)
	11.23 What are the clinical norms for metabolic and physiologic variables in the space-adapted individual (including clinical laboratory and imaging norms)? (1)
	11.24 What are the signs, symptoms or abnormal examination findings (including laboratory) associated with diseases observed in space? (1)
	11.25 What is the risk and incidence of illness and injury associated with spaceflight? (1)
	11.26 What are the essential technologies, methods, resources, skills and training necessary to support physical examination, diagnosis, monitoring and treatment of illnesses and ambulatory health problems in space (including telemedicine, medical informatics, and smart medical systems)? (2)
	11.27 What are the technologies, procedures, and resources necessary for management of medical waste products during space? (2)
	11.28 What are the impacts from and issues related to communication delay on spaceflight health care and telemedicine, and what are the technologies, protocols, and skills necessary for an autonomous health care capability in space as a result of communication delay? (1)
	11.29 What are the provisions, technologies, methods and skills necessary to support environmental health-related diagnosis and monitoring including microbiological, toxicological, noise and radiation issues? (1)
	11.30 What are the optimal protocols, technologies, resources, skills and training necessary to diagnose, monitor, treat and recover patients in space from the expected illnesses and ambulatory medical problems, including but not limited to: (1) - Orthopedic and musculoskeletal problems - Infectious, hematological and immune-related diseases - Dermatological, ophthalmologic, and ENT problems - Nutritional, metabolic, and endocrine disorders - Dental problems - Gastrointestinal and urologic disorders - Behavioral, fatigue and stress-related problems
	11.31 What technologies can be developed and implemented to provide computer-assisted, "smart" modeling of the human system in space that can be used for individual patient modeling, monitoring, diagnosis, and prevention (predictive modeling)? (1)
	11.32 What are alternative approaches to traditional medicine that have potential merit and should be investigated as potential adjunctive therapy for space medicine (such as biofeedback, massage therapy, musculoskeletal manipulation, acupuncture, magnet therapy, etc.)? (3)
Important References:	Not specified

Risk Data Sheet

Risk number	47
Discipline Area	Clinical Capabilities
Risk title	Prevention and Treatment of Space-Induced Decompression Sickness in NASA Operations
Contributing Risk factors	Deconditioning, Improper EVA operations, Musculoskeletal pain due to bends
Risk description	Inadequate methods available for quality health maintenance and for acute health effects control: differential diagnosis between stress fracture and emboli.
Risk Rank (within Discipline Area)	5
Risk Type (across risks)	III
Current risk mitigation status	5
Specific current countermeasure(s) or mitigation(s)	Aggressive Pre-breath Protocols
Specific projected countermeasure(s) or mitigation(s)	Portable hyperbaric treatment; monitoring and diagnostic instrumentation, protocols for different levels and categories of decompression illness
Relationship to other risks within Discipline Area and to other Discipline Areas	Bone Loss, Cardiovascular Alterations, Muscle Alterations and Atrophy, Neurovestibular Adaptation, Environmental Health
Critical Questions:	11.33 What are the strategies to mitigate the risk of decompression sickness during extravehicular activities from the International Space Station and future habitats on the moon and Mars, during training activities in underwater facilities, training activities in altitude chambers, during flight using NASA aircraft, and in research designed to prevent decompression sickness? (1)
	11.34 Given that is possible to mitigate the risk of DCS through exercise, what are the most effective prescriptions involving exercise (type and intensity) and prebreathe duration for different mission scenarios? (1)
	11.35 What are the best models (physiological, statistical, biophysical) to mitigate the risk of decompression sickness in all NASA operations? (2)
	11.40 How can information provided by an in-suit Doppler bubble detector be used to mitigate the risk of decompression sickness in all NASA operations involving decompression? (1)
	11.41 What are the mechanisms of nitrogen washout in microgravity with and without exercise during oxygen pre-breathing? (3)
	11.42 What are the best procedures to accurately quantify and characterize breaks during prebreathe protocols during NASA operations involving decompression, especially during breaks in exercise? (1)
	11.43 What is the role of micronuclei formation, stability, and resolution in blood and tissues on reduction of decompression sickness risk during all NASA operations involving decompression? (3)
	11.44 Under what conditions does the presence of Patent Foramen Ovale (PFO) increase the risk of Type II (serious) decompression sickness in NASA operations involving decompression?
	11.45 Is it possible and what are the DCS risk mitigation options fro interplanetary EVA (e.g., moon and Mars) given that a tri-gas breathing mixture that includes argon is present? (4)
	11.46 What is the role of individual susceptibility, age, and gender on the risk of DCS during NASA operations involving decompression? (3)
	11.47 What are the best strategies, and how do you implement them to treat decompression sickness during all NASA operations involving decompression? (1)
	11.48 What are the available and new technologies needed to provide hyperbaric treatment options on the ISS and future habitats (or vehicles) beyond LEO (e.g., on the moon or Mars)? What are the available or new technologies to deliver oxygen to a patient, including the use of perflurocarbon emulsions? What available new technologies are available to provide life support (e.g., thermal control, telemedicine communications) during hyperbaric treatment in microgravity or on the surface of the moon or Mars? What are the available or new technologies to monitor astronauts with serious decompression sickness? (1)
	11.49 What are the available and new technologies needed to aid in the diagnosis of decompression sickness on the International Space Station and future habitats beyond LEO? (1)
Important References:	Not specified

Risk Data Sheet

Risk number	48
Discipline Area	Clinical Capabilities
Risk title	Difficulty of Rehabilitation Following Landing
Contributing risk factors	Reentry into higher gravitational forces; fluid loading; exercise, fitness, g-suit, deconditioning, impaired response to orthostatic stress; vestibular contributions to cardioregulatory dysfunction, possible chronic impairment of balance function, muscle performance, endurance or strength impairment
Risk description	Post-landing alterations in cardiovascular, musculoskeletal and neurosensory systems resulting in severe performance decrements, injuries, and long term sequela
Risk Rank (within Discipline Area)	6
Risk Type (across risks)	III
Current risk mitigation status	2
Specific current countermeasure(s) or mitigation(s)	Fluid loading protocols (oral isotonic solutions), anti- g suit, exercise protocols, thermal control, body orientation and limited head movement, inflight exercise protocols
Specific projected countermeasure(s) or mitigation(s)	Aerobic exercise, medication, training, protocols for maintaining urine volume
Relationship to other risks within Discipline Area and to other Discipline Areas	Bone Loss; Cardiovascular Alterations; Food and Nutrition; Human Behavior and Performance; Muscle Alterations and Atrophy; Neurovestibular Adaptation
Critical Questions:	11.36 What are the expected effects and risks of long duration spaceflight related to landing, egress and post-landing performance (in various anticipated gravitational environments)? (1)
	11.37 What are the essential technologies, resources, protocols, skills and training necessary for post-landing performance, recovery and rehabilitation (including psychological, cardiovascular, neurosensory, musculoskeletal, and nutritional)? (1)
	11.38 What pre-landing and pre-egress performance and health parameters should be monitored to assure adequate cardiovascular tone, neurological function, skeletal integrity, muscular strength, and endurance? (2)
	11.39 What are the issues related to and resources required for long term rehabilitation and recovery from long duration spaceflight? (2)
Important References:	Not specified

12.0 Multisystem (Cross Risk) Alterations

Risk Data Sheet

Risk number	49
Discipline Area	Multisystem (Cross Risk) Alterations
Risk title	Postlanding Alterations in Various Systems Resulting in Severe Performance Decrements and Injuries
Contributing Risk factors	Reentry into higher gravitational forces; Fluid loading; Exercise; Fitness; G-suit; Deconditioning; Impaired response to orthostatic stress; Vestibular contributions to cardioregulatory dysfunction; Possible chronic impairment of balance function; Muscle performance; Endurance or strength impairment; Prolonged exposure to microgravity and transitions to altered gravity levels upon landing on planetary surfaces; isolated and confined environment; highly autonomous operations with delayed communications
Risk description	As the human adapts to the changing conditions of microgravity, alterations in any one physiological system may affect the function of other systems. The primary issue is to understand how post-landing alterations in multiple systems may result in performance decrements or increased injury, and to identify the preventative or rehabilitation strategies for facilitating post-flight recovery of function and performance.
Risk Rank Order (within Discipline Area)	1
Risk Type (across risks)	II
Current risk mitigation status	5
Specific current countermeasure(s) or mitigation(s)	Oral isotonic solution, anti-g trousers, thermal control, body orientation and head movement protocols for re-entry, postflight adaptation protocols, inflight aerobic exercise, medications (promethazine for SMS), selection criteria, training, radiation risk management procedures, balanced diet
Specific projected countermeasure(s) or mitigation(s)	Acute and chronic diagnostic and monitoring capabilities; smart medical systems ; advanced medical imaging and telemedicine capabilities; optimal protocols for on-orbit management of injuries
Relationship to other risks within Discipline Area and to other Discipline Areas	Bone Loss, Cardiovascular Alterations, Food and Nutrition, Human Behavior and Performance, Immunology, Infection and Hematology, Muscle Alterations and Atrophy, Neurovestibular Adaptation
Critical Questions:	12.01 How do alterations in cardiovascular function associated with spaceflight affect the functioning of other systems? (2)
	12.02 How do alterations in neural, endocrine, and metabolic function associated with spaceflight affect cardiovascular functioning and the functioning of other organ systems? (2)
	12.03 What rehabilitative measures should be applied after mission completion? (2)
Important References:	Medical Policy Board: Medical Procedures and Requirements Document, Third Revision, NASA Headquarters
	Nicogossian, A.E., Huntoon, C.L., and Pool, S.L., Space Physiology and Medicine, Third Edition, Lea and Febiger, PA., 1994

BIOASTRONAUTICS

CRITICAL PATH

CONTROL PANEL

CHARTER

Aug. 30, 2000
(Updated August 28, 2002;
in revision July 30, 2003)

Approved by

John A. Rummel, Ph.D.

Assistant Director for Bioastronautics
Bioastronautics Program Office
NASA Johnson Space Center

J. Sutton, MD., Ph.D.

Director, National Space Biomedical Research Institute

CHARTER

CRITICAL PATH CONTROL PANEL

Bioastronautics Program Office
Johnson Space Center
National Aeronautics and Space Administration

1.0 PURPOSE

1.1 The Critical Path Control Panel (CPCP) will maintain the content of the Bioastronautics Critical Path Roadmap (BCPR), including review and approval of changes to that content and the issuance of directives communicating any such changes. All CPCP directives will be reflected in the content of the BCPR Baseline Document and the BCPR web site.

1.2 The CPCP will review and approve updates to the content of the BCPR following discussion by all participants at scheduled meetings of the CPCP. All items submitted to the CPCP must be reviewed first within each of the Discipline Area Teams, signed by the Team co-leads, and then formally submitted as a change request (CR) to the CPCP for review and disposition. The CR form is included in Attachment 1. Change requests may be submitted at any time to the Executive Secretary of the CPCP. All CR forms and any supporting materials will be collated and distributed to panel members for their review in advance of CPCP meetings. The Discipline Area Team Co-leads will maintain an inventory of all CRs submitted to their team with their recommended disposition of all items. This list will be submitted to the CPCP prior to their scheduled meetings. The CPCP will consider the change requests for approval during scheduled panel meetings. Decisions regarding the disposition of BCPR changes will be based on a majority vote. Minority opinions regarding BCPR changes may be documented for the record.

1.3 The BCPR content, and any recommended changes to that content, will be the responsibility of the Discipline Area Team Leads and the members of those teams. The teams will review and update the information in their areas (including representative references), and develop new information in support of the BCPR. Recommendations to change the content of the BCPR will be made through the CR process.

1.3.1 The Discipline Area Teams will consist of members from NASA Johnson Space Center (JSC) Bioastronautics Program Office (BPO) and the National Space Biomedical Research Institute (NSBRI), to be appointed by, and serve at the discretion of, each organization. Two Co-Leads, one each from JSC and NSBRI, will chair each of the Teams where applicable. The Discipline Areas will include the following:

- Advanced Life Support
- Bone Loss
- Cardiovascular Alterations
- Environmental Health
- Food & Nutrition
- Human Behavior & Performance
- Immunology, Infection & Hematology
- Muscle Alterations & Atrophy
- Neurovestibular Adaptation
- Radiation Effects
- Clinical Capabilities

- Multidiscipline (Cross Risk) Alterations (membership matrixed from other risk areas)

1.4 The CPCP will prepare a baseline document of the content of the BCPR. The CPCP chair and deputy chair will have signature authority with concurrence by the Assistant Director for Bioastronautics, BPO.

1.5 The CPCP will review the BCPR content as needed and, at a minimum, annually. The CPCP will ensure that changes to the BCPR content are thoroughly reviewed, appropriately dispositioned, officially documented, and communicated to the Assistant Director for Bioastronautics, BPO, and other program management and Risk Area Team leads.

1.6 The CPCP will periodically evaluate NASA-funded research and technology activities in the area of human space life sciences in relation to the BCPR, and will recommend changes in program content or direction, as appropriate, to the BPO and to other program management leads.

2.0 SCOPE AND AUTHORITY

2.1 The CPCP is authorized through the BPO Control Board (BCB); the Chairs report to Assistant Director for Bioastronautics, BPO.

2.2 The CPCP will establish, through the BCB, a baseline document of the BCPR within 30 days of approval of the charter.

2.3 The baseline document will be applicable to all NASA-funded research and technology activities in the area of human space life sciences.

2.4 The baseline document will define the elements of the BCPR to be controlled by the CPCP.

2.5 The CPCP will establish a Support Team to handle administrative and functional responsibilities of the CPCP. The Support Team will consist of NASA and Contractor personnel. Operations of the Support Team will be managed by the Executive Secretary of the CPCP.

2.6 The JSC and NSBRI members of the CPCP, appointed by the BPO and the NSBRI,respectively, will serve for a three-year term. All members are voting members.

3.0 RESPONSIBILITIES

3.1 The CPCP will be responsible for reviewing changes and approving all BCPR content, including, discipline risk areas, risks, risk types, risk rankings, critical questions, critical question priorities, risk area roadmaps, deliverables, risk mitigation requirements, risk resolution timelines, and other BCPR content-related items.

3.2 The CPCP will be responsible for developing a BCPR congruence tool for the NASA and NSBRI program managers to use to assess the overall strength of association of individual ground and flight projects and tasks with the BCPR. The CPCP will periodically review and report on the status of NASA-funded research and technology activities in the area of human space life sciences with regard to BCPR congruence and progress, and provide recommendations for future emphasis and funding. A report on BCPR congruence will be issued annually.

3.3 The CPCP Chairperson and Deputy Chairperson will chair all CPCP meetings and will resolve conflicts, disposition all changes, and issue CPCP actions and directives.

3.4 The CPCP will determine the type of review process necessary to properly disposition change requests to the BCPR content, the type of instrument needed to assess NASA-funded

research and technology activities in the area of human space life sciences with regard to BCPR congruence and progress, and the type or format of the annual report assessing the congruence of those efforts with the BCPR.

3.5 The CPCP Support Team will be responsible for the following:

- Scheduling and conduct of meetings.
- Establishing official communications channels between the CPCP and BPO and other external programs, including, but not limited to, the NSBRI, the NASA Headquarters Offices of Biological and Physical Sciences (Bioastronautics Research Division), the Chief Health and Medical Officer, Space Flight (International Space Station Program and Space Shuttle Program), and other necessary program offices.
- Receiving and processing for review and evaluation all submitted program changes and documentation.
- Processing for distribution, review, evaluation, and decision-making, all CPCP change requests submitted by potential requesters.
- Issuing directives identifying the decisions of the CPCP.
- Issuing minutes of all CPCP proceedings.
- Transmitting, tracking and closing of actions issued by the CPCP.
- Establishing and maintaining a change and action accounting system that maintains a record of all CPCP proceedings, directives, actions, and baselined documentation.
- Archiving of CPCP records.
- Interacting with web site personnel to assure the integrity of the web site content per the existing directives of the CPCP.

3.6 Members of the CPCP will attend all CPCP meetings if possible, when absent, voting is permissible via other means (such as telephone, video-conference, or proxy). Panel members are responsible for ensuring that all CPCP directives and actions are responded to in a timely fashion. The CPCP will consist of twelve (12) members, as described below. A quorum will consist of no fewer than seven (7) members, including no fewer than two (2) of the four (4) NSBRI members.

- CPCP Chairperson (JSC)
- CPCP Deputy Chairperson (NSBRI)
- Executive Secretary
- JSC BPO Members (3)
  - Human Adaptation/Countermeasures
  - Medical Systems
  - Advanced Human Space Technology Program
- NSBRI Members (3)
  - Human Adaptation/Countermeasures
- Astronaut Office (1)
- JSC BPO Chief Scientist
- NASA Headquarters Office of Biological and Physical Research Life Sciences Bioastronautics Research Division representative (1)

All internal Directorate programs and external programs (including International Space Station, Space Shuttle, and Exploration) are invited and encouraged to participate in open CPCP activities.

3.7 The Discipline Area Teams will meet, formally or informally, during the course of the year, at the discretion of their respective team leads, to review the BCPR content in their areas and develop new information to provide to the CPCP through the CR process. Disicipline Area Team leads and members may attend CPCP meetings to discuss upcoming CRs, or to provide information related to the progress of BCPR risk reduction and mitigation in their respective areas. The BCPR Discipline Area Team Co-leads will maintain an inventory of all

CRs submitted to their team with the recommended disposition of all items. This inventory will be provided to the CPCP prior to scheduled meetings.

Attachment 1 - Change Request Form

1. CR Number ___	OFFICE OF BIOASTRONAUTICS CRITICAL PATH CONTROL PANEL *CHANGE REQUEST FORM*	2. Page 1 of ____

3. CR Title	4. INITIATOR
	ORGANIZATION
	PHONE
	EMAIL
	FAX

5. CR TYPE (Administrative Use Only)
DISCIPLINE AREA
RISK
RISK FACTOR
CRITICAL QUESTION
DELIVERABLE
TASKS
ROADMAPS
TIMELINES
OTHER _____

6. Description of Change (Use a separate CR for each change request; and, explain what is being changed using "*Change to"* and "*Change from*" language to describe each change):

7. Justification for Change (Include impact if change not incorporated)

8. Provide Documentation to Support Change (list specific references and/or data sets, or cite levels of evidence, if applicable)

9. Disposition of CR and Signature of Risk Area Team Co-leads	11: Comments
NASA: __ Concur __ Do not concur* **Signature:** _____ **Date:** _____ **NSBRI:** __ Concur __ Do not concur* **Signature:** _____ **Date:** _____ • If not concurred, provide justification (next page)	

CPCP CR *(Continued)*

In the space provided below, provide justification for CR: cite levels of evidence (see attached) or provide other supporting material, as necessary.

Current Guidelines of Practice for Clinical Levels of Evidence

Level 1 = Evidence obtained from a systematic review of all relevant randomized controlled trials

Level 2 = Evidence obtained from a least one properly designed randomized controlled trial

Level 3-1 = Evidence obtained from well-designed controlled trials without randomization

Level 3-2 = Evidence obtained from well-designed cohort or case control analytical studies, preferably from more than one center or research group

Level 3-3 = Evidence obtained from multiple time series with or without the intervention

Level 4 = Opinions of respected authorities, based on clinical experience, descriptive studies, or reports of expert committees